....AND HE WILL BE YET WISER. Proverbs 9 9

THE TEACH YOURSELF BOOKS
EDITED BY LEONARD CUTTS

GOOD SOIL

in the
FARMING and
AGRICULTURE
section

Prepared under the special
direction and scientific
Editorship of

Dr. S. GRAHAM BRADE-BIRKS
M.Sc. (Man.), D.Sc. (London)

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GOOD SOIL

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THE ENGLISH UNIVERSITIES PRESS LTD.
LONDON

First printed, 1944
Fourth impression, 1949

TO

ALL WHO HAVE FOUND AT

WYE

THEIR INSPIRATION TO ADD

TO OUR KNOWLEDGE OF

THE SOIL

Made and Printed in Great Britain for The English Universities Press Ltd., London by C. Tinling & Co., Ltd., Liverpool, London, and Prescot.

EDITORIAL PREFACE

WHEN the editor is also the writer of the book he introduces, he can hardly say what he would of other authors under the same circumstances—true though it may be! He may, however, in this case say quite impersonally that this book is written by someone keenly interested in Good Soil, who, from long experience as a teacher of the subject and as a University examiner in it, knows something of the work of agricultural students, and about the kind of information that is likely to be useful to the farmer and the general reader.

S. GRAHAM BRADE-BIRKS.

PREFACE

THIS book is written for the serious student of the soil. It is an attempt to bring together sufficient detailed information about different kinds of soils to give a general picture of the soil-mantle, its properties, its origin, its constitution and its diversity.

When farmers and soil-scientists, alike, speak of "soil" they use the term in two senses, the general and the particular. When it is stated that everything the farmer produces comes directly or indirectly from *the soil*, it is a general statement on the same plane as the assertion that *the cow* gives milk. The general may mask the importance of the particular, for just as one cow gives better and more milk than another, so there are many soils which differ from one another in constitution and capability. In writing and reading this book it is important to keep the distinction in mind.

Although this volume is directed more particularly to agricultural students, it is hoped that it will be useful to practical farmers, to students of other branches of knowledge and to general readers.

Chapter I is a general introduction. It is not essential to the book, but it is hoped that it will serve to indicate the attitude of mind that is essential to a clear grasp of the subject in hand.

If we want to describe or define any particular soil, so that we can recognize it again when we meet with it, or be able to compare it with other soils, we must know what are important among soil-properties; consequently, part of this book goes into this in some detail, pages 100–133.

The origin and development of soils is dealt with in

Chapters IV and V. This is, in part, a geological matter, for rocks have contributed most of the bulk that is found in soils. Some geological information is given in Chapter III, pages 42–56.

The composition of the soil is well known in a general sense. This part of the subject is treated on pages 64–67. But in addition to this constitution which is common to all soils, there are those features which we might almost call the *anatomy* of soils, and these, while different in different individual soils, are found to be similar in soils which are members of the same soil-group of the world. If we wish to understand this "anatomy" we shall find a study of the soil-profile a first requisite. The *soil-profile* is defined in Chapter VI, pages 119–124, and a number of illustrations represent individual soil-profiles (see figs. 52–55 etc). We can then obtain a broad view of this part of the subject by a comparison of the profile characteristics of the different *great soil groups* (Chapter XIV, pages 211–242).

The factors that control soil development are set out in Chapter XII (pages 190–197), but these are limited by regional and local conditions and the results of different conditions are seen in different kinds of soil regionally and locally. The regional differences come out in the soil pattern of the world and are seen when we take a world-wide view of the soil-mantle; it is hoped that Chapters XIII and XIV make this clear, pages 198–242. There are Chapters in the book on the study of the soil in the field (XV), soil-structure and other physical properties (XVI), and an account of some of the commoner soil minerals which certain students will find useful (XVII). Chapter X is a farmer's chapter dealing with compatibility between soil and crop-plant, a subject which calls for more research. Some aspects of soil erosion are examined in Chapter

XI, which contains an account (communicated to the author by Mr. J. H. Stapley) of wind erosion in the Eastern Counties.

To the individual farmer who wants a scientific description of his soils or a soil map of his own farm there will be interest in the way in which soils are defined for future recognition. This is covered by Chapters VI–IX, pages 97–162 and by part of Chapter XV (see pages 243–254).

I am indebted to a large number of friends and colleagues for advice and help in one way and another during the preparation of this volume. Mr. Basil S. Furneaux has given me constructive criticism at all stages, and among other Wye colleagues to whom I am obliged are Mr. V. R. S. Vickers, Dr. N. H. Pizer, Messrs. S. G. Jary, H. B. Bescoby, H. H. Glasscock, John Sankey, Cornelius Davies, H. Barkworth, Ian Clewley and W. J. Ball. Through the courtesy of the American Embassy in London I have been emboldened to make much use of the publications of the United States Department of Agriculture, while through the kindness of the authorities at Australia House I have been able to use material published under the auspices of the Commonwealth Government, particularly work by Professor J. A. Prescott. Professor G. W. Robinson has kindly provided me with a map prepared in his department at Bangor, and Profesor H. H. Read, F.R.S., has given me helpful advice; to Dr. Hugh Nicol of Rothamsted I am indebted for advice about soil-bacteria, and to Dr. H. G. Thornton, F.R.S., also of Rothamsted, I owe the original drawing which appears as my Figure 17. Mr. J. H. Stapley of the School of Agriculture, Cambridge, has given me the account of soil erosion already mentioned. I am grateful to Dr. L. Dudley Stamp and to Dr. E. Cecil Curwen for their help.

Mr. D. V. Fletcher has been very kindly critical. From references made to sources in captions, it will be seen how far I am in the debt to Mr. Basil S. Furneaux, Dr. Hilda Brade-Birks, and others for illustrations.

In the preparation of diagrams of soil-profiles I have made use of descriptions and illustrations published by numerous pedologists, and it is almost impossible to assess the debt to any individual scientist; I hope that if I have failed to give due acknowledgment it will be realized that the omission is inadvertent. The same is true in the preparation of maps. In compiling the soil map of England and Wales I have had the help of colleagues and friends, and Mr. Keith Carpenter has given me the benefit of his skilful pencil; for this map I have also used information given on the International Soil Map of Europe.

To all who have helped me to produce this book I express my sincere thanks.

S. GRAHAM BRADE-BIRKS.

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(UNIVERSITY OF LONDON)
WYE, KENT.

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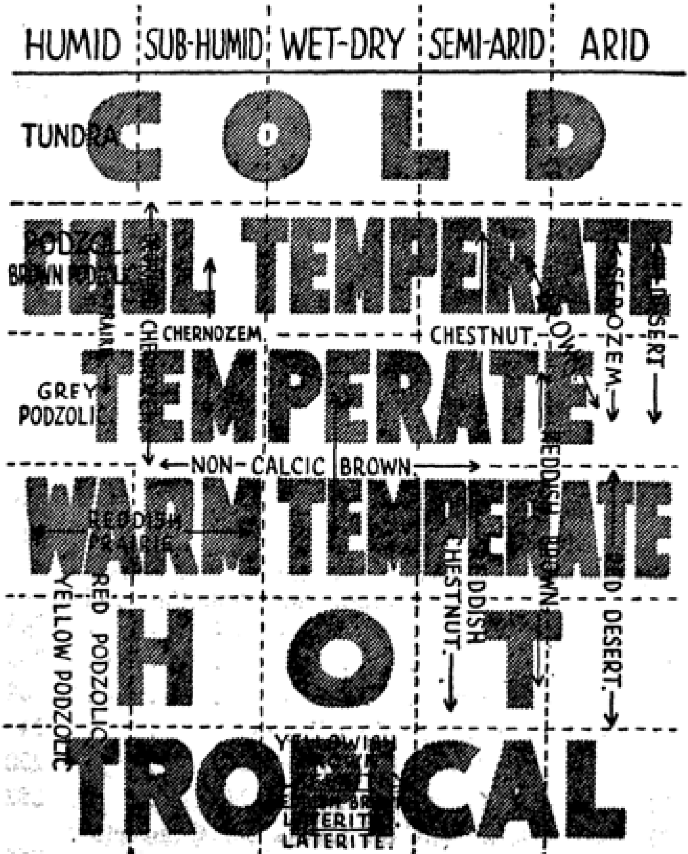


Figure 1.

The Relationships of Zonal Soils and World Climates.

In this diagram the reader will find the kind of Zonal Soil he may expect to occur under any given climate.

Compiled by S.G.B.-B.

CHAPTER I

INTRODUCTION

We open the subject with some general considerations which reveal the modern attitude of mind towards soil-studies. We speak of the soil-mantle and note its diversity. A first definition of the soil is framed. After speaking of the plant and the soil and also of soil constituents, a fuller definition is adopted. Diversity among rocks leads to diversity among soils. There are different soils for different crops. Other points are discussed: the root in relation to the soil—plant foods in the soil—the modern outlook—the soil-profile—the soil-auger. The best use of the soil is briefly mentioned and the limited possibilities of soil improvement are indicated. The great importance of regarding the soil as a part of the natural world is given special emphasis. In later chapters some of the threads that are broken off here, are taken up again.

> "The income of a farm is derived from the sale of crops and stock which are directly or indirectly the product of the soil. . . . It is, therefore, very necessary for a farmer to have an intimate knowledge of the soil. . . ."
>
> —VICTOR FISHWICK, in *Good Farming.*

WHEREVER the farmer is at work, there you will find the soil. Over the greater part of the land surface of the globe it covers the solid rocks of the earth's crust

like a mantle. In fact it is appropriately called *the soil mantle*, and when we speak of " the soil " in general terms, this is what we mean.

The first and most important fact to recognize about the soil-mantle is that in its nature it is very diverse,

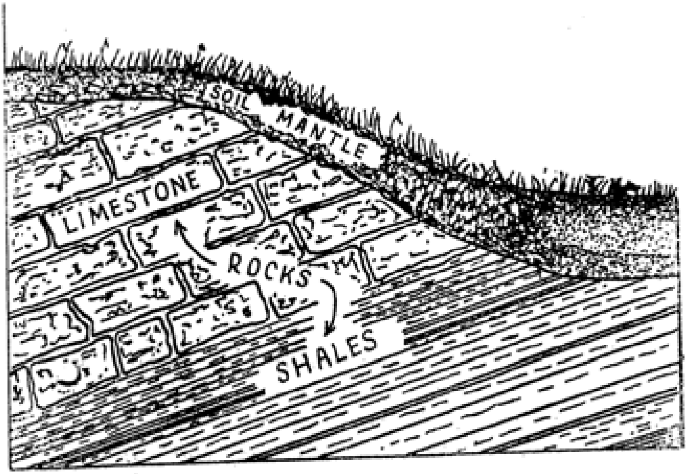


Figure 2. The Soil-Mantle.

The diagram shews a section through soils overlying limestone and shales. Differences in soil properties are indicated and the covering of the rocks by the soil-mantle is shewn. The soil at the left end is a Rendzina; at the right there is podzolization; these terms are explained in later pages. *Drawn by S.G.B.-B.*

that it is not the same everywhere, not even, as a rule, the same all over a single farm. It is obvious, for example, that some parts of it are thin and that others are deeper. Again some parts are wetter than others, and this may be due either to differences of rainfall or differences of situation. In some places " the soil " is very easily worked, that is to say,

THE DIVERSITY OF THE SOIL-MANTLE.

the plough can readily be drawn through it: in the farmer's parlance it is " light "; on the other hand there are places where it needs an extra horse to plough a furrow and the land is said to be " heavy." Is your land wet or dry? Is " the soil " shallow or deep? Is it heavy or light? These questions—among many we might ask—are enough to remind us that *the soil-mantle* is made up of different soils and that an individual farmer may have several of them on his own farm.

While it is true that the soil-mantle is very diverse, it is also true that all agricultural soils, the world over are alike in certain respects. The farmer's plants everywhere grow in the soil. So we can make an elementary definition of the soil by saying that *it is the stuff in which plants grow.*

The parts of the plant in the soil, the roots and the underground stems, are supported by the soil, protected by it from drying, supplied with water to drink, and nourished by the mineral foods that occur, in solution, in the soil moisture.

CONSTITUENTS OF THE SOIL-MANTLE.

Then about the constituents of the soil-mantle: a considerable proportion of " the soil " comes ultimately from the rocks. This is the mineral part of the soil and it always consists of clay, silt and sand.* The clay, silt and sand occur in different proportions in different soils, but they are all three present in all soils. Even a very sandy soil may contain nearly twenty per cent. of clay intimately associated with a little silt and a lot of sand. Mixed up with the mineral matter are, of course, air and water. But these are not the sole constituents of the soil. There are, in addition, organic materials: the decayed and decaying products of animal and plant life which are

* See figure 37, page 140.

collectively known as *humus*. The humus is intimately incorporated with the mineral matter of the soil, and it provides ample food and a very suitable medium for the life of bacteria, millions of which occur in every crumb of surface soil.

The soil-mantle as we see it to-day covering the rocks of the earth's crust and providing a root-hold for plants is the product of a long weathering process of development, the work of many of the agents of nature.

THE SOIL-MANTLE.

Thus we arrive at a point where we may frame a definition of the *soil-mantle* (or of "the soil" if we use the term in a general sense) as *the natural weathered material in which plants grow and by which they are supported and supplied both with water and mineral foods. The constituents of the soil-mantle are mineral particles—clay, silt and sand—incorporated with air, water and humus, the last-named providing a medium for bacterial activity.*

THE ROCKS OF THE EARTH'S CRUST.

Beneath the soil-mantle lie the rocks of the earth's crust. These rocks are many and various. Some are hard and compact like granite; others such as clay, are soft; others again are loose and unconsolidated like sands and gravels. The geologist calls all these, hard and soft and loose alike, "rocks" because they all form part of the earth's crust. Because there are so many different rocks which differ from one another in composition, there are many individual differences in composition among the individual soils of the soil-mantle which have derived their mineral constituents from weathered rock. Differences of underlying rocks also provide differences in the natural drainage and therefore in the moisture conditions of the soils above. Where water

passes easily and rapidly through a rock, the soil above will readily be drained of its surplus rain-water. If an impervious rock lies beneath a soil, impeded drainage of the soil is to be expected. All this is well illus-

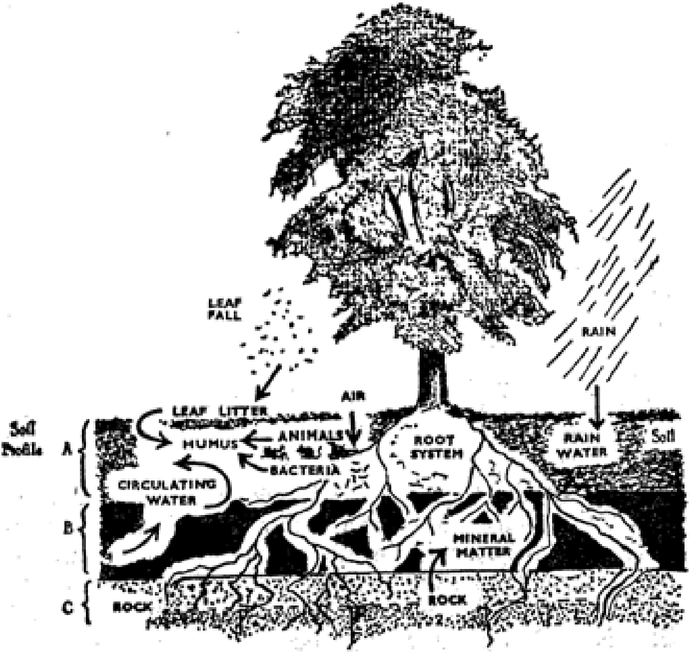


Figure 3. Soil-Constituents.
Diagram to shew the origin of the air, water, humus (organic matter) and mineral particles which compose the soil.
Drawn by S.G.B.-B.

trated by figure 25, page 110. There are many other factors which differ from place to place; native vegetation and climate are outstanding examples, and it is therefore not surprising to find that the soil-mantle

consists of a multitude of soils, many thousands of them, if we take a world-wide view.

Lime is a mineral constituent of the soil, which is of special interest to the farmer. Sometimes it is naturally present in an individual soil, sometimes it is necessary for the farmer to add it, if he wants to get the best out of his land.

EXAMINING THE SOIL.

When a farmer buys or rents a farm it is a great advantage to him to know beforehand what the soils are like. If the land is heavy, not only at the surface but some feet below as well, it will affect the natural drainage and also make the soil heavy to work. Being wet land the crops on it will grow slowly in the early summer and the harvest will be late. All this will have an influence upon the costs and profits of the farm. If a man is skilled at examining the soil and knows about its properties he will be able to recognize the important features which reveal drainage conditions and to determine, on the spot, what it will be like to work.

Some of the best soils in England are deep loams. A loam is neither very heavy nor very light. If deep it is retentive, within itself, of sufficient moisture to tide a farm crop over most of the periods of drought that occur in this country and, provided that its situation is such that it cannot become water-logged, its natural drainage will be excellent for most agricultural purposes. If the loam is naturally rich in lime that is an extra point in its favour. The depth of the soil gives great scope to the farmer in the choice of suitable crops, but, naturally, the price or rent of such land, if its nature is fully known to its owner, is high.

Then there are light soils, some of them deep, some shallow. Some of them are very valuable especially for market gardening. If the natural drainage is free,

such soils are liable to dry out in summer. Examination of the deeper parts of the soil will give the experienced observer a lot of useful information about such soils and enable him to assess the value of the land.

The foregoing are examples of the kind of information about soils that it is possible to obtain from their examination in the field.

ROOTS AND LEAVES FEED THE PLANT.

After a farmer has drilled his land with wheat the individual seed germinates and begins to grow its roots down into the ground, the blade shoots up and appears above the surface. Both roots and leaves feed the plant. The leaf takes in from the air the gas carbon dioxide, and receives water from the roots by way of the stem. From carbon dioxide and water it manufactures starch, which is very important in building up the plant.

The roots below ground absorb both water and the mineral foods dissolved in the soil moisture. Some of these mineral foods come from the natural soil itself, some of them have probably been put there by the farmer because he knows they are needed. It is wonderful how deep it is possible for the roots of agricultural crops to go in search of food and water. Sometimes the plants have no need to go so deep and it may on occasion even be an advantage to the farmer to give a plant less root depth than it could use. If, for example, root growth is restricted in a dessert apple, the fruit is more attractive than it would be in a deeper soil which promotes vigorous growth, and the value of the crop is increased by the restriction. In dealing with plants, we have to decide in our own minds what we are expecting of them, fruitfulness or vigorous vegetative growth. In clover and grass

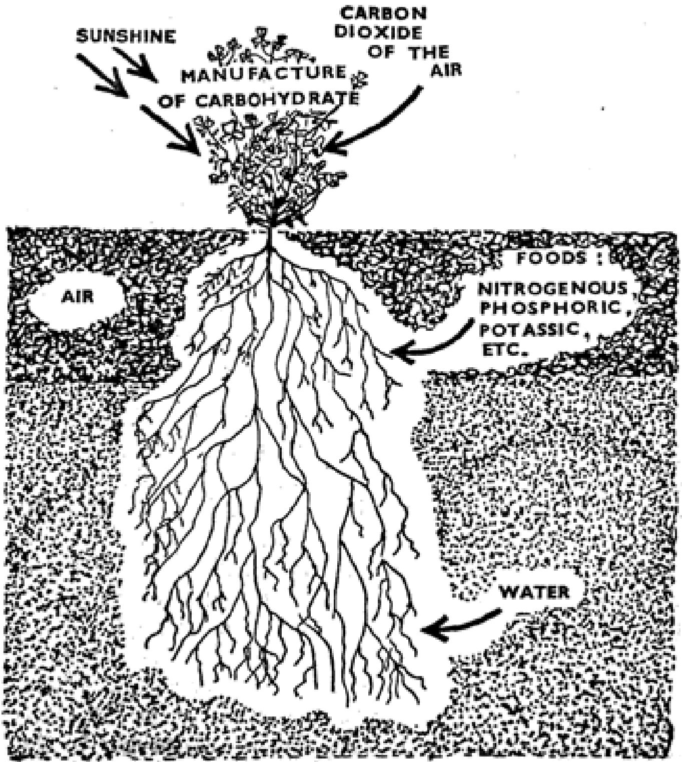


Figure 4. How a Plant gets its Food.

Most people realize that a plant gets nitrogenous, phosphoric, potassic and other foods from the soil through its roots, but it is often forgotten that a very much greater weight of food is obtained through the leaves where starch (carbohydrate) is built from carbon dioxide (absorbed from the air) and water, by the agencies of sunlight and the green matter (called chlorophyll) of the leaves.

Drawn by S.G.B.-B.

grown for the feeding of farm animals, the latter is required, but in cereals and fruit-trees the former. If vigorous growth is required above ground you must have vigorous root development, and this implies plenty of room for the roots, a good deep friable soil. *Adequate* root-space is needed for the healthy fruiting plant, but if there is some restriction below ground there will be less active growth of stems and leaves and greater fruitfulness is to be expected. Take the case of barley which often does well on a rather shallow chalky soil. If a soil in which barley is sown is deep, roots may extend to more than six feet and food and moisture available at considerable depths can thus be used, but if the soil be shallow, and the rooting system thereby be more restricted, barley of a better malting quality will probably result.

Plant roots obtain as food from the soil :—

(1) *Nitrogen* in the form of nitrates. These are the ultimate products of bacterial activity in the soil. Nitrogen in appropriate compounds is needed by plants, especially for vigorous growth and for reproduction.

PLANT FOODS IN THE SOIL.

(2) *Potassium Salts*—generally the farmer calls these potash. When there is plenty of potash available to the plant, its health and quality are promoted and the efficiency of the leaves in producing starch is increased. For this reason available potassium salts in the soil are of especial benefit to such plants as potatoes, cereals and sugar-beet, which are crops that the farmer grows to produce starch or sugar.

(3) *Phosphorus Compounds*, usually termed phosphates in agricultural circles. When, for the needs of

the plant there is enough phosphorus present in available compounds in the soil, rapid growth is promoted and maturity is early. Since phosphorus is present in protoplasm, the living substance of all animals and plants, it is essential for life. It occurs in plants in its greatest concentration in seeds. In rocks it is present in the mineral apatite (calcium phosphate) which, though widespread enough, is not usually present in large quantities, and therefore in the soil also is not usually present naturally in great concentration; nor does all that is present occur in a form available to the plant. The English farmer supplies phosphorus as phosphate to his soils in the forms of basic slag, bone-meal, and superphosphate.

Thus we may say that the staple foods of a farmer's crop are *carbon dioxide* taken from the air and used with water by leaves to make starch and similar substances, and the *three kinds of nourishment* taken in by the roots:—*nitrates, potash* and *phosphates*. Plants also need water which they can take up through their roots. But they do not want too much of it or the roots will be drowned; they need air in the soil for good health, and sufficient depth of friable earth for the proper development of the root system.

FOOD SUMMARY.

Only small quantities of lime rank as food for plants, but sometimes lime is also needed in the soil in quantities sufficient to neutralize acids. At the same time lime, properly used, produces other good results in the soil, such as encouraging the useful work of bacteria, improving the physical condition of soils by giving those that are heavy a crumb or granular structure and preventing some fungous diseases. Like most good things, however, you can sometimes have too much of it.

In addition to all the food mentioned, plants in

order to keep themselves healthy, need other chemical elements in suitable compounds—often they are only required in minute quantities and a little more may be positively injurious—magnesium, sulphur, iron, manganese, boron, copper, and zinc. The deficiency of some of them shews curious results in certain crops. A good example is the different effects of manganese

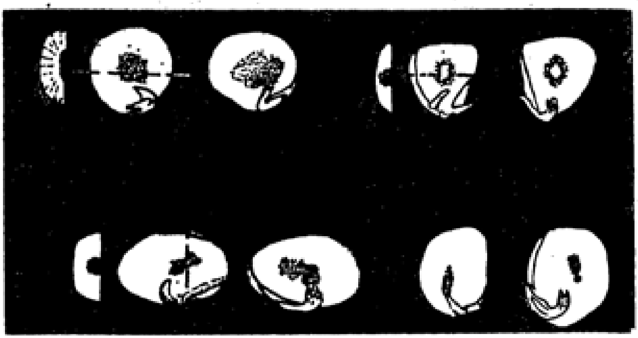


Figure 5. The Effect of Mineral Deficiency in the Soil.

Four pea seeds opened and (in three cases) one of the cotyledons cut through (the direction of the cut being shewn by a dotted line) to shew the symptoms of a disease known as Marsh Spot which is due to a lack of manganese in the soil. Top left: shallow pockets of discoloured tissue covering a wide area of the seed. Top right: narrow, deep pockets of grey shrunken tissue. Bottom left: brown patches punctuate with darker brown spots. The bottom right: pea shews brown patches; the plumule is affected. Five-eighths natural size.

Courtesy of H. H. Glasscock.

deficiency on different cereals. In the case of wheat, barley and oats, oats shew a marked paleness of the older leaves and patches on the leaves die when there is a need of manganese in the soil. Wheat is affected to a lesser extent by the same degree of deficiency, while barley may shew no ill symptoms at all.

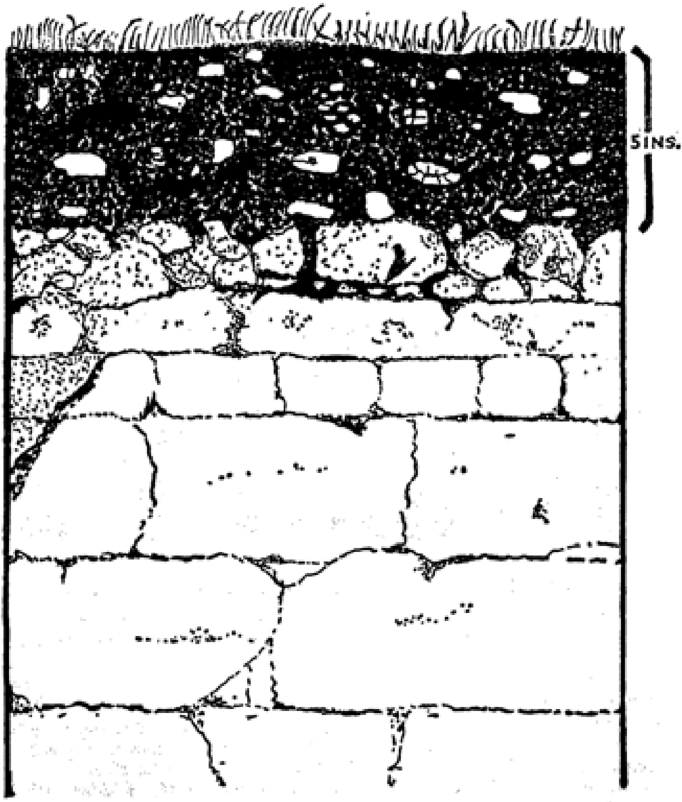


Figure 6. A Dwarf Soil.

Soil-profile of a Rendzina. Five inches of soil with a typical granular structure overlie Chalk (a soft earthy limestone). Fragments of Chalk (calcium carbonate) occur in the surface soil. In this instance the soil is a black loam.

Drawn by S.G.B.-B.

AN OUTSTANDING CHANGE.

An outstanding change that has come about in recent years in our study of the soil has been in the great attention paid to its deeper layers. In Great Britain on cultivated land *in a typical case* there is generally about nine inches of surface soil, frequently greyish brown in colour. It contains all the main constituents of the soil that have already been enumerated, i.e. mineral particles, humus, air and moisture, and is teeming with millions of bacteria invisible except with a powerful microscope. Dig a little deeper and the soil is paler, often light brown, sometimes grey. A little deeper still, perhaps eighteen inches down, the soil has a brighter colour, it may be mottled orange, red and yellow. At this depth we are in the subsoil, and it is heavier and more compact than the surface material turned by the plough. Go down a little deeper still, another foot or so, and the rock is reached. In examining the soil in this way we are looking at the results of many seasons of alternating rain and sun, many long years of soil-forming work by the agents of nature, so that distinct layers have been produced in the soil. This production of differences of colour, differences of compaction, differences of texture and so on give us what is technically called a *soil-profile*. I have just indicated the characteristics of a typical English *soil-profile* without going into too great detail, but you will find many other types of *soil-profile* if you dig down into the ground in various places. Take an exceptional case for contrast. On some hill in the south or south-east of England you may see a dwarf soil, only five inches deep. Fragments of chalk are mingled with this shallow depth of granular black material and then at five inches from the surface you come upon the solid white rock, the chalk. At the other extreme of depth

I have seen a sandy soil in England into which roots of chestnut penetrated to a depth of more than forty feet, no doubt mainly in search of water.

THE SOIL-AUGER.

If soils differ so much in depth and the underlying rocks have such an important effect upon drainage as has been indicated, it is quite clear that the modern tendency of the soil-scientist to emphasize the importance of *soil-profile* is well grounded, and that the farmer who wants an intimate knowledge of his own soils must also pay attention to the *soil-profile*. There is an implement of simple construction called the soil-auger which enables anyone with a little practice to examine the deeper layers of the soil easily and quickly. It is a device which withdraws samples of the soil with ease down to a depth of 3½ feet, and this is generally sufficient to supply most of the information that a farmer requires.

Some parts of the country are noted for special crops. Parts of Kent grow exceptionally large quantities of fruit and hops. Essex is noted for wheat. The red soil of Dunbar is famous for its potatoes, said to be the best in Britain.

THE BEST USE OF THE SOIL.

What, we may ask, are the factors that make for this local success of certain crops? Does the soil play an important part in determining the special crop? These are natural questions. Speaking generally, trial and error and long experience of success with a crop have revealed a suitability of the soils of the district, and it is success that is responsible for the firm establishment of a farming practice. But there are other considerations. In a district that has long had a specialized crop, individual farmers and farm labourers alike under-

stand the special cultural operations, the right implements and equipment have been acquired, the farms are laid out to deal with the crop and the neighbourhood has facilities for handling and selling the product.

Many factors operate in determining what it is best to grow on a particular farm, and because the nature of the soil is one of them the quotation at the top of this chapter is true. In nature there is perfect compatibility between plant and soil, for every soil has its natural vegetation. On the farm this wild vegetation has to be superseded by a cultivated crop. The farmer only wishes to grow a limited number of kinds of agricultural plants, and a soil that is good for one purpose may not be good for another.

COMPATIBILITY.

There are two ways of approaching the question of compatibility between plant and soil. We may, on the one hand, begin with the soil and ask ourselves what it will grow best, or, on the other hand, we may select a crop, and then, having found out what the soil requirements of the plant in question are, as regards moisture, depth, reaction, texture and so on, may look for a soil suitable for growing it. If we begin with the soil it probably means we already have a farm. If we begin with the plant that we wish to grow, it is likely that we are looking for suitable land on which to raise our selected crop.

Within certain limits the farmer can modify his soil. If its natural drainage is deficient it may be possible to improve it by land drains. If the soil is acid in reaction liming will correct it. If one or more of the food requirements of the crop are lacking, farm-yard manure or artificial fertilizers may be applied to meet the need. But there are some fundamental features of the soil which it is not within

IMPROVING SOILS.

the farmer's power to alter. Great changes are not to be expected in soil texture; even by the most efficient management we cannot expect to turn a very heavy soil into a loam. It is not an economic possibility in the elevated parts of Great Britain to correct excessive natural drainage nor can a shallow soil be converted into a deep one.

A NATURAL OBJECT.

The soil-mantle with its teeming population of microscopic life is a part of the natural world, and has taken many thousands of years to reach its present stage of development. Consequently no individual soil is a mere mixture of sand, silt and clay, with a little decayed plant debris thrown in, such as a gardener might make to fill a flower-pot. It is a natural object with properties all its own and if the farmer regards it in this way he will see why different soils have different food and water requirements, different cropping capabilities, and are affected in their own special ways by cultural operations, so that while one soil can be ploughed with advantage the day after heavy rain, another will not be sufficiently dry for a week.

There is nothing strange in speaking of the natural history of birds or of the beasts of the jungle, of fern and flower or even of minerals, rocks and fossils, but when we come to the subject of the soils of the farm it may seem rather strange to talk of their natural history. Nevertheless this idea is a very important one in studying the soil. In good soil we shall find processes of development at work, substances in solution circulating from one part of the soil to another, the temperature of the soil varying, the teeming life of its microscopic inhabitants rising and falling in numbers and activity. These things remind us of the physiological changes that

are always at work in plants and in the bodies of animals. When we look at the soil-profile we catch a glimpse of something akin to the structure of a plant or the anatomy of a farm animal. With such ideas in our minds, this substance in which plants grow almost comes alive and at least we realize that the good soil, so long regarded as dirt by the ignorant and as a system of mechanical and chemical mixtures by the learned is indeed as much a part of nature as the plant that grows in it or as the horse that turns its mellow mould into the promise of triumphant harvest.

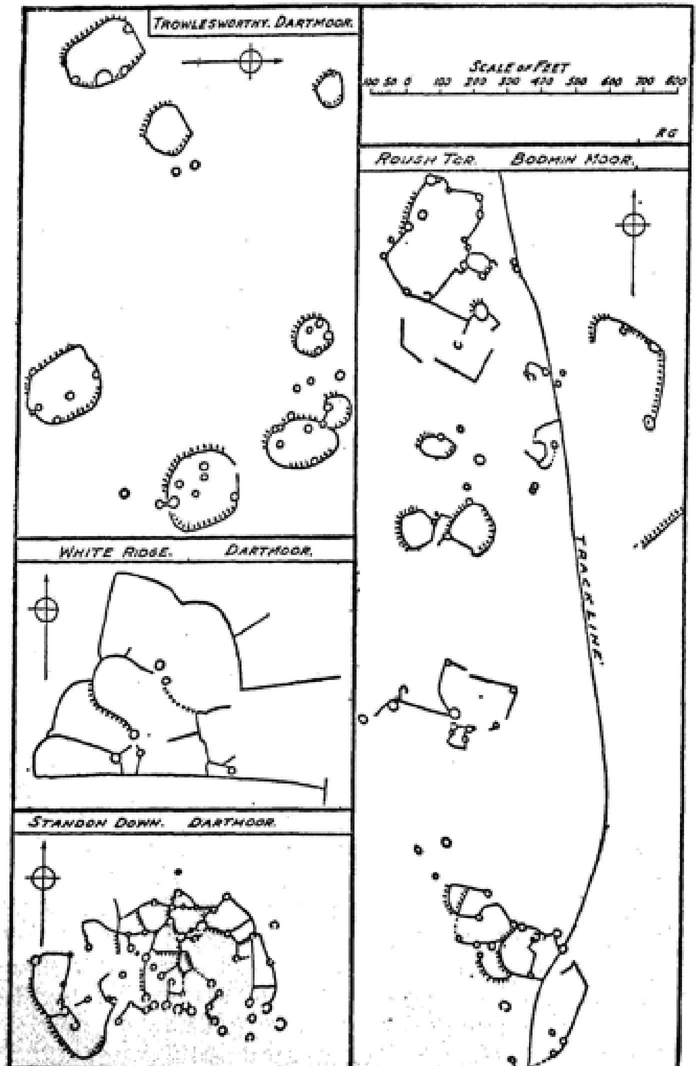


Figure 7. Maps of Ancient Corn Plots.
with Huts, probably Early Bronze Age.
Courtesy of Dr. E. Cecil Curwen.

CHAPTER II

SOILS IN THE NATURAL WORLD

The cultivation of the soil is an ancient craft. In this chapter we return to the subject of the diversity of the soil-mantle with which the farmer is concerned. There is regional diversity; the soils of the wheat-belt, for example, are different as a whole from the soils of the tropics. Within regional diversity of kind there is diversity of individual soils, even on the same farm. The study of these diverse soils has, in recent years, emphasized the fact that every soil has natural properties. Some natural properties of the soil are well known to the farmer, who thus finds himself on common ground with the modern student of the soil. The chapter concludes with a reference to the origin of the soil.

AN ANCIENT CRAFT.

THERE are remains of little enclosures on Dartmoor which were cultivated fields some three thousand years ago, fields in which the farmer of the Bronze Age grew his corn. Cultivation of the soil must have already been an ancient craft even in those remote days before man in this country had learned to use iron. Ever since, man has been labouring to cultivate his land and raise his crops year after year. The foundation of all that the husbandman has been doing all through long centuries, and is doing to-day, to feed his family and his farm animals, is the soil, so that if anyone in the world

ought to know a good soil when he sees one, it is the farmer.

Soil is the first pre-requisite of farming. Almost everywhere soil covers the solid rocks of the earth's crust and forms the so-called "soil-mantle" of the earth, a very good and descriptive name for it. Soils are not all and everywhere the same, not even all of the same kind; to realize this we only need to think of the great contrasts provided by the Black Soil (Chernozem) of the Wheat-belt of the Soviet Union, the wide expanses of Ashy-grey Soils (Podzols) in Europe and North America, and the great regions of Lateritic Soils in the Tropics. And when it comes down from these broad contrasts to the farmer's own experience of the land that he and his family have cultivated, he knows there are different soils on different fields, in fact sometimes two, or even more, recognizably distinct soils in one and the same field.

THE INDIVIDUAL SOIL IS A NATURAL OBJECT.

When we turn to study the soil-mantle scientifically and to consider the great soil-regions of the world and the individual soils of each farmer's own personal experience, there is one outstanding fact which has been increasingly emphasized in recent years, the fact that each soil is a natural object. We may here make a useful comparison by considering something which we shall more readily recognize, from its familiarity, as a natural object such as a tree or a cow or a piece of coal. Let us take the case of the cow: this animal consists of so much fat and muscle and bone and blood and so on. We can get figures from books to tell us the exact proportions of these, but when we hear a cow mentioned we do not normally think of these proportions at all. We think of a useful domestic animal, living, eating, reproducing

its kind and providing man with milk and meat: when we see a cow we recognize it as a part of the natural world; from our previous experience we know its general pictorial outline as well as the shape, proportions and relationships of its various parts, we notice too its colour and perhaps we ask its owner about its milk-producing capacity. All these properties are peculiarly those of the cow and it is by these characteristics that we know the animal to be a part of the world of nature and itself, therefore, a natural object. It is in the same sense that a soil is a natural object, not merely a mixture of various constituents, for it too has characteristics all its own, intrinsic properties as we may call them, which proclaim the soil to be a part of the same natural world in which the tree, the cow and the piece of coal all have their place. The full significance of this idea about individual soils will become more apparent as the study of the soil-mantle proceeds, but it is both useful and important to state it at the outset.

A SOIL HAS NATURAL PROPERTIES.

Look at the soil of your own field or garden. Pick up a handful of it newly turned by plough or spade; run it through your fingers and you will at once see that the great bulk of it consists of mineral matter, revealing itself perhaps in pebbles and tiny stones, and almost certainly in sand-grains and clay, all of which are natural materials embodied in the soil.

But there is more in the soil than the mineral matter; frequently the uppermost part of the soil, the top nine inches or so, is darker than the soil below, and one reason for this is that the top part of the soil has been enriched and darkened by the decay of plants, the remains of whose dead roots and stems and leaves you may still see there.

Again, the soil is moist because, intimately incorporated with the mineral matter, there is water, which has been added, generally as rain from the air but sometimes by circulation from underground sources.

There is one more point; if we remember that undisturbed soil contains innumerable cracks running down into its substance from the surface of the ground, and that there are crevices and crannies everywhere in the soil as well as tiny spaces between the smallest constituent particles, it is quite evident that there is a great deal of air in most soils. But these four important materials: mineral matter, the products of plant-decay (generally called *humus*), water — of course containing substances dissolved in it — and air are not just thrown together haphazard; they are found to be associated in a most complex manner, related to the way in which the soil has been developed. And the development of the soil is a result of the action of many natural agencies working for a very long time. The soil so constituted and developed exhibits, upon close study, a long series of natural properties, many of which are closely inter-related.

We shall soon proceed to a close examination of the natural properties of the soil, so we shall here content ourselves with little more than a bare recital of a number of them.

ENUMERATION OF SOME NATURAL PROPERTIES OF THE SOIL.

All soils have a large bulk of mineral matter, the mode of origin of which provides us with data for the description of soils. The colour of the soil, its natural drainage and its topography are properties of great use in identification. In recent years the vertical section of the soil, technically called the soil-profile, has been a most useful instrument

of soil-study, and it is a feature to which we shall return shortly. Then chemical reaction (which will be explained), climate, and the soil-texture (i.e. whether a soil is "light" or "heavy") are additional properties of the soil and so too are such things as its depth, its stoniness, and its structure. There are many points in this mere enumeration which will require expansion and elucidation, but the very mention of a dozen properties of the soil is sufficient to shew what an interesting and complex subject we have taken up.

If the soil-scientist walks with him over his friend's farm he will find that the farmer recognizes individual soils. One is lighter than another, one is fit to plough sooner after a period of wet weather than another. Between the two men there is common ground because both look at the soil *in the field*, and both assess it by natural properties. This comes out still more as the two friends discuss the origin of this soil or that, they say something of its geology, recognize its colour as different from that of an adjacent field and note how important differences of natural drainage can be in determining the value and nature of a soil, affecting as these do the possibilities of cultivation after wet weather and the moisture content of the soil after long periods of dry weather. Topographical differences are recognized as being of great importance in determining the relative values of different soils. The farmer knows from his own observations what his soil is like below the surface down to a depth of at least a foot or two. This leads to a discussion about what a man of science calls the *soil-profile*. They also speak of those other characteristics which we have already enumerated among the natural properties of the soil. And the

THE FARMER'S POINT OF VIEW.

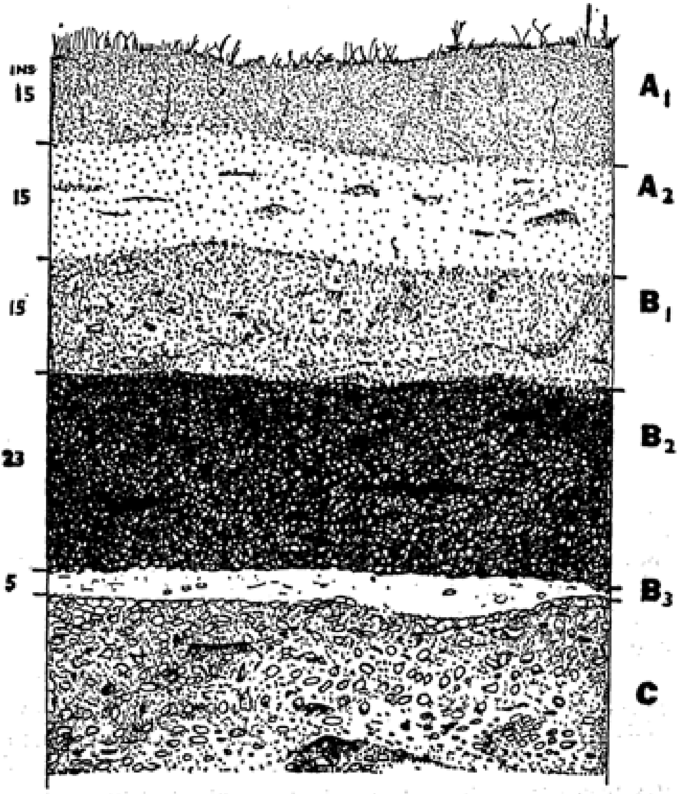


Figure 8. **Typical Soil-Profile.**

This drawing shews well-defined horizons in a Brown Podzolic Soil (Willesborough Loam). It has a strongly cemented and compacted B_2 horizon overlying a clayey horizon B_3. These characteristics shew the soil closely to resemble a Planosol (see page 239). But the drawing is inserted here to illustrate the principal features of a well-developed soil-profile. The extent of each zone of the profile is indicated by the marginal index which corresponds with particulars given on the opposite page.

From a photograph by Basil S. Furneaux. Drawn by S.G.B.-B.

Typical Soil-Profile

(See Figure 8 opposite)

Brown Podzolic Soil resembling a Planosol. (Willesborough Loam) Willesborough, Kent, under permanent pasture.

A_1. 15 inches fine brownish grey loam, rich in roots.

A_2. 15 inches lighter coloured brown loam.

B_1. 15 inches cohesive loamy sand slightly darker than A_2 with a variable broken flint content. Particles shew patches of surface deposit of compounds of iron (indicative of illuviation).

B_2. 23 inches irregular sand and gravel of a dark Vandyk brown colour, cemented together in some places.

B_3. 5 inches clayey gravel (in the close vicinity this layer consists of 2 inches of cohesive coarse sand and 2 inches of very cohesive clay with weathered limonite (see page 276) in it).

C. (The underlying rock) consists of speckled sands and gravels.

result of all this discussion between the farmer and the man of science is the establishment of the important principle that the soil-scientist to-day views the soil very much from the same aspect as.that of the intelligent farmer, expanding and putting into scientific language the information that individual farmers have gathered for themselves from observations and experiences of their own soils, correlating that knowledge with knowledge about other soils, systematizing the experience of many people in different parts of the world and welding the scattered information into a scheme of knowledge that shall be applicable to the study of all soils everywhere. Thus we may say that the modern study of the soil is an extension of the farmer's method, which, of course, means that it is a very practical method and one that is of the greatest service to the farmer or gardener that makes use of it when it has been elaborated and systematized for him by the soil-scientist.

The new attitude of mind towards the soil—the method of regarding each soil as a natural object in which plants grow—gives us an approach which constitutes the science of pedology (Greek πέδον, *pedon*, soil; λόγος, *logos*, word, science) and it is the object of this book to explain what the findings of pedology are. The pedologist studies the soil in the field and takes note of natural properties so that his findings can be applied for the best utilization of each soil. In this way, that most desirable co-operation of farmer and scientist, upon which so much agricultural success to-day depends, is established and maintained.

MODERN SOIL-SCIENCE.

It is as true of the good soil as it is of the Eternal City that it was not built in a day. The newly-turned mellow loam behind the plough is no mere admixture

of mineral grains with humus, air and water as some of the old writers might lead us to suppose, but it has a long and complicated history.

THE ORIGIN OF THE SOIL.

The soil has grown into its present state by a more lengthy, but nevertheless as natural a process as the growth and development of the beech tree or the oak in the nearby wood.

The text-books written fifty years ago told us that the soil was weathered rock: that is a bald statement, but there is more than a grain of truth in it, for without rock and without weathering of rock, there could be no true soil. So, any enquiry about the origin of the good soil must take the rock and its constituent minerals into account. The rocks of the earth's crust are, of course, a special and a separate study, and as soon as we begin to enquire about them we are concerning ourselves with the science of Geology. (γῆ, *ge*, the earth; *logos*, science).

CHAPTER III

THE GEOLOGY OF THE SOIL

Much of the bulk of soil material comes originally from rocks, so some attention is paid in this chapter to those facts of geology which are of importance in understanding the origin of soils. Especially we consider: how the earth began, the forces of nature, rocks as soil-formers and the production of different kinds of rocks (igneous, sedimentary and metamorphic).

THE GEOLOGY OF THE SOIL.

THE story of the origin of the planet upon which we live is a very fascinating one, but it is not part of our present task to consider it in any detail. All geologists are agreed that long ages ago the earth was very hot and in a molten condition. Then, by a long and gradual cooling, measured in millions of years, it became a globe with a solid crust and eventually it was cold enough for rain to fall and streams to flow. From that time on, the conditions prevailing on the surface of the earth have been much the same in kind as those with which we are familiar to-day. From the time when the outer surface of the earth first solidified, the rocks of the crust have been weathered by atmospheric agencies much as the stones of an old building or the face of a cliff can, to-day, be seen to have been weathered. The result of weathering is the production of rock detritus, sometimes powdery

or dusty, sometimes sandy or gritty. The raindrop and the brook and the river, in the earliest ages of the earth's history, carried down the debris to lower levels where the hollows were filled with the waters of the first ocean. So the wasting of the mountains produced a sediment which accumulated in layers on the floor of every sea and lake. It was the beginning of a process which has been going on ever since. To-day every stream is carrying, downhill, sand and silt and clay which have been derived from the wastage of the land, and all the lakes and seas of the world are receiving these materials. While the rivers were playing their part volcanoes were pouring out lava, and earth-movements were crushing and uplifting, folding and depressing the primeval crust. In the earliest days of the earth volcanic eruption and earthquake must have been more frequent and more violent than they are to-day, but these same agents are still at work producing changes which are sometimes sudden and catastrophic, though volcanic action is now comparatively rare and earth-movement often quiet and gradual.

It was not until the globe had cooled for a very long time indeed that it was cold enough for ice and snow to be formed, but when at last this stage was reached all the conditions for rock destruction and soil formation were complete.

From all this it will be seen that we believe that from very early times the phenomena now exhibited by nature around us have had their part to play in changing the face of the earth. Running water, the oceans, frost, ice, snow, wind, volcanoes, earth-movements, all these and others have been at work for long ages making changes which are still going on. In a word, natural forces known to us to-day have been of the same kind, though different at times

in degree, from very remote ages in the history of the earth.

ROCKS AS SOIL-FORMERS.

It has already been mentioned that over the greater part of the surface of the globe the rocks of the earth's crust are covered by soil, this material with which we are now specially concerned. The soil-mantle is the product of the activity of a large number of natural agencies working upon the rocks of the earth's crust.

And so we return to a point to which we have alluded before. If we are to understand the soil, we must first turn our attention to the rocks, since from them such a large part of the raw material for soil-formation is obtained.

The Production of Rocks.

IGNEOUS ROCKS.

The first rocks of the earth's crust were formed by the cooling of molten material. Similar rocks are being formed to-day wherever molten material is cooling; it may be at the surface on the slopes of a volcano where lava has been poured down from the crater and is now solidifying, it may be in the pipe of a recently active volcano or it may be deep down in the earth where some vast hoard of molten mineral-matter is gradually losing heat and passing into the solid state. Rocks formed in this way, of whatever age, are known as igneous rocks (from Latin *ignis*, fire). Igneous rocks naturally vary very greatly in mineralogical, and therefore in chemical, composition, and their structure may be glassy, finely crystalline, or coarsely crystalline. Granite, syenite, and basalt are examples of igneous rocks, they differ from one another in mineralogical composition,

but all have been derived from molten materials. You will find all the detailed information you want about igneous rocks in special works on geology and petrology (the science of rocks), but in Appendix I, page 279, of the present book is an outline classification of these rocks which readers may find useful.

While the earth was still extremely hot, and before it had solidified, the heavier parts of the molten material (or *magma*, as it is called) gravitated towards the centre of the globe while the parts lighter in weight (which eventually became the crust) accumulated on the outside. This remained the relative arrangement when the crust at last solidified. The weight of the whole earth is about 5½ times that of a similar volume of water, while the crust itself is much lighter. The outer part of the crust of the earth (about 2½ times as heavy as water) is very rich in the chemical elements, silicon and aluminium, and for that reason has appropriately been called the Sial. The Sial rests upon somewhat heavier materials of the magma (about three times as heavy as water), a deeper part that behaves rather like a viscous liquid. This deeper part of the crust is designated the Sima from the fact that it consists of silicon in combination with other elements, of which magnesium is the most important. From the composition of the crust to-day we know that the first formed rocks of the earth consisted in overwhelming proportions of free silica and silicates, whereas other substances present were proportionally insignificant in quantity. While the Sial, then, is very rich in silica and in aluminium silicates, the Sima largely consists of more basic, heavier silicates.

Incidentally, the fact that the primeval crust consisted almost entirely of silica and silicates explains (a point seldom clearly understood) why silicates—

and silica—are so important when we are considering the mineralogical composition of rocks and soils, and rock-forming and soil-forming minerals. Taking igneous rocks as a whole, F. W. Clarke (in *The Data of Geochemistry*) without claiming that it is exact, gives the following computation of their average percentage composition:—

	per cent.
Felspars	59·5
Hornblende and Pyroxene (the group including Augite)	16·8
Quartz	12·0
Biotite	3·8
Titanium minerals	1·5
Apatite	·6
	94·2

The remaining 5·8 per cent. consists of less abundant minerals. If we take the first four lines of the above table we see that the silica and silicates there included account for over 92 per cent. of the igneous crust of the earth.

SEDIMENTARY ROCKS.

Sedimentary rocks: We have already mentioned another mode of rock-formation which has been in operation from very early times. Age by age rivers have carried down debris disintegrated from the land, and this, as sediment, has been deposited layer by layer on the floor of ocean and lake. An accumulation of this kind has often, in the long history of the earth, been consolidated by pressure, cemented together by such substances as oxides of iron to form a sedimentary rock and

eventually, as a result of earth-movement, has been raised from beneath the sea to become dry land. Every continent tells the same story, and such sediment may constitute its open plains, form its rolling hills or even make up its loftiest mountains. Thus plain, hill and mountain provide evidence not only of their own marine origin but of the gigantic forces too, which have been at work to lift them to their present elevations. The remains (called *fossils*, which means

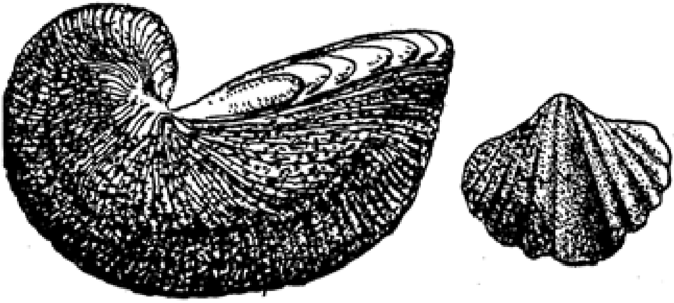


Figure 9. **Two Fossils**

from Liassic (Jurassic) rocks: a Lamellibranch (left) (*Gryphaea arcuata* Lam.) and a Brachiopod (right) (*Spiriferina walcotti* Sow.)
½ natural size. *Drawn by S.G.B.-B.*

"things dug up") of shell-fish and of other marine animals found embedded in the rock of high hills are good evidence that what has just been said is really true. Any rock which has been formed as a sediment in the way described is called a sedimentary rock. Sandstone, chalk, clay and shale are examples of sedimentary rocks. There are obviously two ways in which we can classify sedimentary rocks; we can group together all the different sandstones that have ever been formed in the long history of the world,

(some of them were formed many millions of years ago, some are in process of formation to-day), but their age, in this instance, does not matter, they are all sandstones; similarly we may group all known limestones together, all shales, all clays; such a classification, based upon the nature of the mineral matter in rocks and ignoring all other considerations is called a lithological (from λίθος, lithos, stone) classification. But it is obvious that we can classify sedimentary rocks in another way, viz.: according to their age; in this way we shall find shales and sandstones of one geological period grouped together and separated from other shales and sandstones of a later age by the chronological nature of the classification employed. Some indication of the chronological classification of sedimentary rocks will be found in Appendix II, on page 280 at the end of this book.

A limited number of widespread substances or groups of substances which are not quantitatively noteworthy when the crust as a whole is considered have yet an important role to play in rock and soil. Outstanding examples are provided by limestones and iron compounds. Limestones are sedimentary rocks consisting principally of calcium carbonate, while iron compounds by their remarkable powers of giving colour to rocks and soils, even when present in minute quantities, play a part altogether out of proportion to the amounts present.

The ultimate source of iron compounds found in rock and soil is the comparatively small amount of iron entering into the composition of the minerals of igneous rocks.

Limestones principally owe their origin ultimately to the lime in the lime-felspars of igneous rocks. In the process of rock decomposition this lime was

made available for transport from land to sea and then by raindrop, brook and river was carried down with the debris of rock to the ocean and there passed into solution in the sea-water. From the sea-water it was extracted by marine animals, some large and highly organized, others microscopic but very numerous, and was used by them for building up their calcareous hard parts or skeletons. When these animals died their soft parts disintegrated in the water, but their skeletons (bones and shells, and so on) sank and sometimes formed a deposit upon the floor of the sea. Such a sediment frequently consists of nearly pure calcium carbonate and by consolidation becomes a limestone. If by earth movement the floor of the sea is raised this limestone may become dry land and, if the elevation is sufficient, the ancient sea-floor may be re-modelled as a range of limestone hills built of fossil animal-skeletons, some of which are obvious to the naked eye while others are so small that we need a microscope to see and study them.

In addition to the limestones which owe their origin to the selective work of animals in the sea, there are limestones and other less widespread deposits of calcium carbonate which are either direct or bacterial precipitates from sea or fresh water. The most striking of these are dolomite or magnesian limestone (so called from the high proportion of magnesium carbonate which it incorporates) and the calcareous deposits of springs (tufa) and caves (stalactite and stalagmite).

METAMORPHIC ROCKS.

Metamorphic rocks: When molten materials are poured out upon the the surface of the earth by volcanoes the rock over which the lava flows is affected by the heat and by some of the chemical

constituents of the lava; clays are baked, limestones and granite undergo physical changes, chemical changes may even be produced in individual minerals and so on. Similar changes are produced deep below the surface when movements of the molten materials occur there. Changes have often been wrought in the nature of rock by the great pressure of overlying materials and by the effects of heat, especially

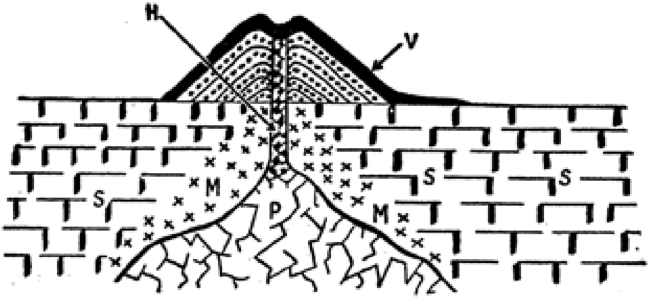


Figure 10.

Diagram to shew the Relationship of different kinds of Rocks.
P, H, and V are igneous rocks (see Appendix I, page 279). P, Plutonic; H, Hypabyssal; V, Volcanic (here seen on the slopes of a volcano). S is limestone, a sedimentary rock (see page 46). M is metamorphic rock (see page 49). *Drawn by S.G.B.-B.*

in the presence of subterranean moisture. Both igneous and sedimentary rocks are changed in this variety of ways, and the products are in each case known as metamorphic rocks. To this class of rocks belong marble, gneiss, schist and slate.

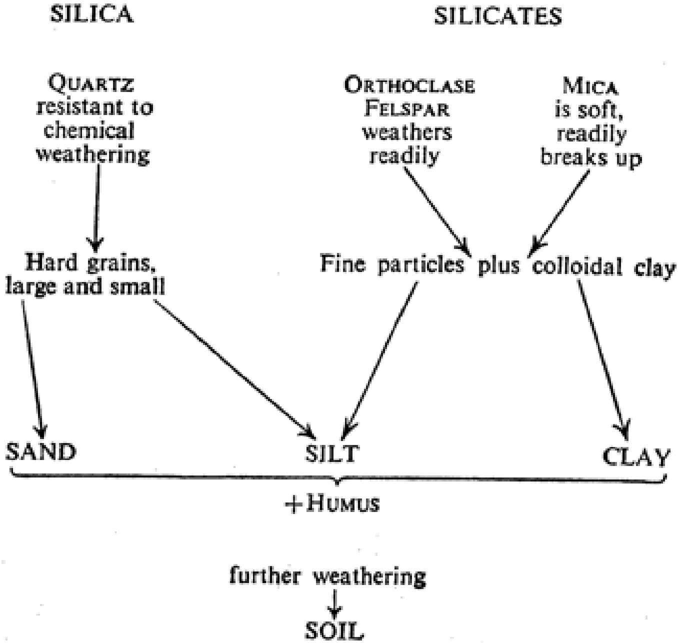
PROPERTIES OF ROCK.

We have now sketched in outline a view of the rocks as the source of the raw-materials for soil formation, but we may find it useful to consider some features, both of their mineral-

ogical composition and physical constitution, which influence the course of soil-formation, or pedogenesis, as it is termed. The state of division before and after the weathering, consolidation, looseness or compaction and cementation of the particles, softness, mellowness, hardness and like properties of rock and rock-detritus are all of interest to the pedologist because upon them depend a number of the properties of the resulting soils and the ease or difficulty with which soils are developed in the different kinds of parent material.

Igneous and metamorphic rocks in general conform to the popular conception of a rock in being hard and resistant in a fresh state, but many of them readily break down as a result of weathering into loose and even powdery debris. When quartz is present in these rocks it resists chemical weathering and may be expected to survive most of the disintegration processes and appear at the end of them mainly as sand. Finer particles of quartz may be found in silt. Silicates present will undergo hydration and their final product is clay. Examples of igneous rocks which will well illustrate this are basalt and granite. Basalt, consisting almost entirely of silicates without quartz, is reduced by decomposition to a mass consisting mainly of clay, but no doubt including particles of a size which belong to the silt grade. Granite, consisting of quartz, orthoclase felspar and mica (i.e. of silica and silicates) is weathered into sand, silt and clay in a manner that is illustrative of the way in which hard rocks as a whole are converted first into the raw materials for soil-formation, and then, by further weathering and admixture of humus, into soil.

The following diagrammatic representation summarizes the course of events:—



In the small percentage of constituents that are neither silica nor silicates igneous rocks include numerous minerals, and those that are hard and also very resistant to weathering, like Rutile, find their way into the sand fraction of the resulting soil; this is also true of some silicates like Zircon and Tourmaline. Staurolite is an example of a silicate occurring in metamorphic rocks which behaves in a similar way.

There is an important point to bear in mind when considering igneous and metamorphic rocks as sources of the raw materials for pedogenesis, namely that, except in the south-west of England, the igneous

and metamorphic rocks of Great Britain occur in glaciated regions, which means that, except the highest peaks, the whole of the rock material exposed has been subjected to the grinding action of ice with the consequent complication of much added rock detritus in all stages of comminution from large boulders through pebbles, sand and silt to clay.

If we take into account the presence or absence of glaciation we have only to consider the mineralogical composition of any igneous or metamorphic rock to see what the course of events is likely to be. But there remains one metamorphic rock, marble, which stands alone, and this may be considered as on the same footing as limestones with which we are about to deal.

Among sedimentary rocks the pedologist views limestone as very distinct from any other deposit. Its calcium carbonate is readily soluble, especially in carbonated water (see page 79), and the residue though relatively small in amount, may accumulate over a long period from a very great quantity of limestone, and so produce a conspicuous bed of material, which is usually, from its ferruginous and colloidal nature, a red clay. In part at least, the Clay-with-Flints found overlying the Chalk in parts of south-eastern England is a residue of this sort. Apart from this loss of calcium carbonate by solution, there is further weathering of limestone, especially by the action of frost and biologic agents, so that the uppermost layers of limestone tend to break up, and many small fragments of rock may become incorporated in the soil, and this is true both of hard kinds, like the Silurian and Carboniferous limestones, and of very soft varieties such as the Chalk.

The remaining sedimentary rocks comprise a long series of materials which naturally have many different

physical characteristics. Speaking quite generally, the oldest sedimentary rocks (see Chronological Table in Appendix I, page 279) are the hardest, most fully cemented and most compact, while, on the whole, those of most recent origin are least consolidated.

NATURAL CEMENTS.

In the case of the thoroughly consolidated sedimentary rocks it is of interest to know something of the natural cements which are responsible for holding the once loose particles together, for some of these cements are easily decomposed or dissolved, and washed out, and the results are separation of the particles and disintegration of the rock. Other cements are very resistant to change and so the rocks in which they occur stand up well to the natural forces of rock destruction. These cements have often been carried into the spaces between the particles by water in the first instance. Frequently they have been precipitated from solution. It is, in this connection, instructive to see a small ferruginous or calcareous stream running over a sandy seashore and by deposition of iron compounds or calcium carbonate between the particles of sand on the shore converting a loose incoherent mass of sand into a sandstone, just in the very limited track of the little watercourse.

A good way to realize the nature and work of cements is to examine closely a red or yellow sandstone in which the grains are sufficiently large to be easily seen. In a typical case it will be recognized that the proportion of cement to sand is very small. The cement in this case is an iron compound, hæmatite (red) or limonite (yellow) and the thin layer of this that covers one sand-grain is in contact with and adherent to the cement covering adjacent sand-grains, thus the whole mass of grains sticks together. These

two ferruginous cements impart their red and yellow colours respectively to the rocks in which they occur.

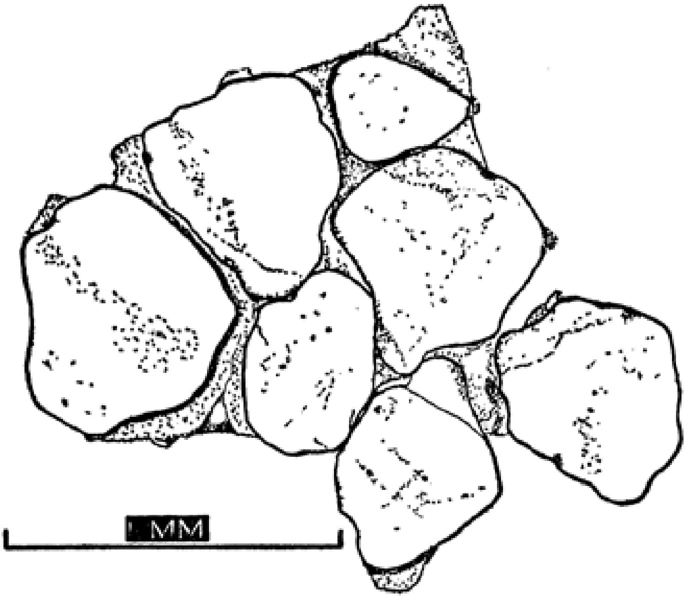


Figure 11. Cement.

Seven grains in a Red Sandstone, shewing the cement which holds the particles together. (Red Sandstone, Penrith, Cumberland.) Much magnified (forty-four times) by the microscope. The scale is one millimetre long. *Drawn by S.G.B.-B.*

Other natural cements are silica, hydroxide of aluminium, hydrated aluminium silicate (clay), carbonaceous matter, barium sulphate (barite), calcium carbonate, calcium phosphate, calcium sulphate, and calcium fluoride. Some of these, like silica and barite resist decomposition or solution well,

others such as calcium carbonate and hematite are easily removed. Upon these properties of the cement depend the ease or difficulty with which the particles of the rock are separated from one another and the rock itself is disintegrated.

CHAPTER IV

HOW SOILS ARISE FROM ROCKS

Plants need sufficient room in the soil for the growth of roots. This chapter shews how an adequate depth of soil originates. Taking the earth's crust as a whole, there is a great choice of materials from which soil can develop. These materials range from hard rocks to drifting sands. In loose materials plants often become readily established because there is plenty of scope for growing roots. Hard rocks must be broken down into fine debris before a soil of any depth can be formed, but very simple plants can even grow on a rock surface and help to break it down.

THE DEVELOPMENT OF SOIL.

FOR the initiation of the development of soil from a hard and consolidated sediment, plant life must become established. Very simple plants can grow upon the surface of the rock and aid in breaking it down so as to provide sufficient depth of debris for the roots of more highly organized vegetation; this, in turn, by growth in life and decay after death, helps to produce a deepening soil. A vigorous vegetation requires ample room for root development and this may be provided after a long period of gradual weathering of the rock in the manner just indicated, or it may be brought about more rapidly, also by weathering agents (the subject of weathering is considered at length, pp. 70–95.) In

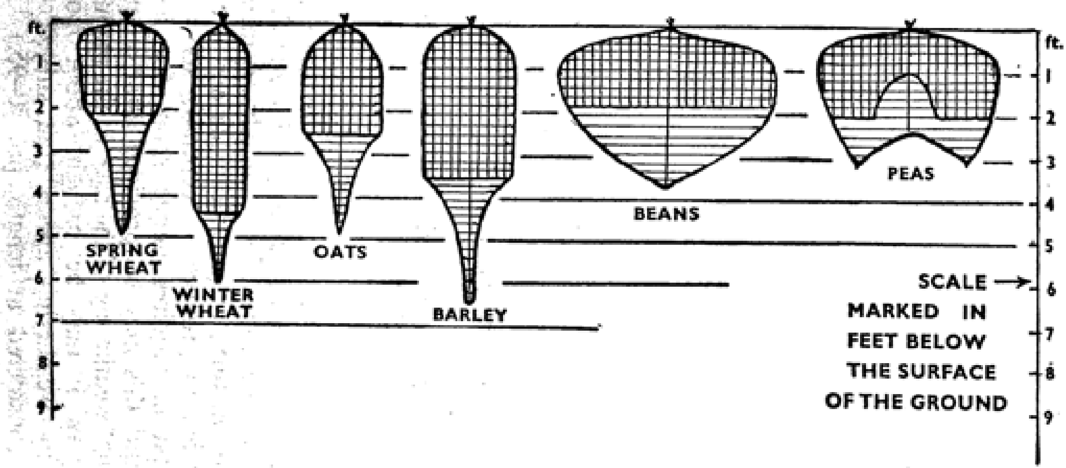


Figure 12. **Root Systems of Corn Crops.**

The shape of the system is shewn in each case for soils in which full development (not necessarily the best for cropping) is possible. Vertical and horizontal scales alike. The cross-hatched portion of each diagram shews the working depth. Based on the work of Professor J. E. Weaver and his associates.

Drawn by S.G.B.-B.

either case the ultimate result is the production of material which will support the larger plants.

ROOT-SYSTEMS.

It may be remarked here that though a good deal of study has been made in recent years of the root-systems of agricultural and horticultural plants we still know all too little of the subject. Weaver illustrates the fact that the roots of beet may go down nine feet into the ground in search of mineral foods and water, which is quite in line with the behaviour of the roots of other cultivated plants and yet we know that greenhouse plants like tomatoes or carnations can find most satisfactory conditions for root growth in a depth of one foot, or even less, of good soil over concrete; but, of course, in this case the manurial and water conditions of the soil are properly controlled. Then again, in some of the famous Romney Marsh pastures the range of root development is restricted to the top three feet or so of the soil by the occurrence all the year round of waterlogged conditions at about that depth. In these three feet of well-aerated soil which contains ample plant food and has plenty of readily available water at hand, the grasses of this world-renowned region seem to find unrivalled conditions for optimum development.

In strange and complete contrast with the hard rock that we have considered, there are loose and drifting sands of coastal dunes moved about from place to place by the wind. Here the wit of man has been taxed to find plants to take root in the unstable material, and it is only by skilful planning that the problem has been solved. While the surface of the hard rock upon which the alga or other lowly plant grows is not yet soil, because disintegration is only just beginning, the grains of the sand-dune

are in such a state of complete disintegration that they can only gradually become soil as the marram grass and other plants become established and add humus while they conserve moisture, so that eventually the particles may be rendered cohesive and other soil characteristics can be induced.

Gravel and sand are among the loosest of the raw materials for soil formation and as they are found in alluvial, marine and glacial deposits they are very widely distributed in the British Isles; sand may also occur, as we have seen, as a wind-borne accumulation. It is easy to appreciate that under some circumstances plants will readily establish themselves in such extremely loose materials and begin the complicated processes of pedogenesis. The roots of plants have an unrestricted range in such a deposit and can grow without hindrance in any direction in the search for food and water.

There are sandstones so little consolidated that they differ but little from loose sand in their physical and soil-forming properties. This is true, for example, in Kent, of the sandstone of the Folkestone Beds where the plant in the surface soil has practically an unrestricted range for its growing roots. We once studied a sand-pit face in this material at Smeeth and here the roots of chestnut went down some forty feet or so.

Other geological materials, as distinct from developed soils, in which there is freedom for root-development include loams, silts, loess and brick-earth. Loams and silts occur in many parts of Great Britain as alluvial or glacial materials and are found as components of river-terrace deposits as well. It was formerly usual to recognize Plateau Loam as a distinct deposit, but it is now mapped as part of the Clay-with-Flints; nevertheless to the pedologist the Plateau

Loam is so different from the heavy-textured typical Clay-with-Flints that it has to be regarded as a

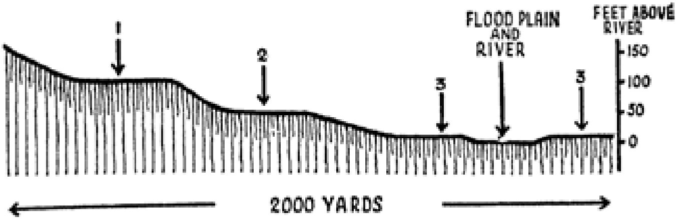


Figure 13. River Terraces.
Three terraces, the levels of a valley floor at three, earlier periods in the river's history, are marked 1 (the earliest), 2, and 3 (the most recent).
Drawn by S.G.B.-B.

separate entity. All these loams and silts are quite loose deposits, quite unconsolidated and admirably suited for conversion into soil.

LOESS. Loess is a wind-borne and therefore finely-divided material widespread over Europe and Asia. Sometimes (as is frequently the case with some of the loessal brick-earths of S.E. England) it has been re-sorted to some extent by water and in this process other materials have been incorporated with it, especially in its upper part. It is typically a fine-grained, compact, porous, cohesive (but not usually cemented) silt and its chemical reaction varies in accordance with the origin of its particles; calcium carbonate may or may not, be present. Being itself a product of disintegration it is in a condition to respond quickly to soil-forming processes and soil characteristics are readily imposed upon it. So ready for conversion into soil may such geological material be that it is possible, in Kent for example, successfully to plant a farm crop or fruit such as cherries,

in a disused brickyard from which the upper part of the brick-earth (loess), including of course the soil, has only recently been removed, without any other preparation than would be accorded to a surface soil in the same district.

OTHER DEPOSITS.

Coombe deposits and colluvial debris also provide a depth of comminuted mineral substances as raw material for the development of soils (pedogenesis). Coombe deposits owe their origin especially to the work of seasonal mud-laden streams which brought debris, often in frozen masses, down to lower ground from hilltops and slopes when thaws set in each spring under the extremely cold conditions of Britain's Pleistocene climate half a million years ago (see Chronological Table, Appendix II, page 280). The materials vary much in their nature and may include coarse rubble, fine silts and clays. Colluvial debris is material washed down by surface water and accumulated at lower levels, especially as the result of heavy rain-storms and in periods of much wet weather.

Under the designation of "boulder clay" (or till) is included an exceedingly wide series of geological materials ranging from stiff (clay) to very light (sand) and from calcareous (limestone debris) to siliceous (sandy detritus) and from smooth and stoneless deposits to accumulations of pebbles and boulders, some of the latter many tons in weight. All these constituents of "boulder clay" are alike in one particular, they owe their origin to the work which ice accomplished over all Britain north of the Severn and the Thames during the glacial period in Pleistocene times (see Chronological Table, in Appendix II, p. 280). The lighter kinds of "boulder clay" provide raw materials not unlike some of the river-borne

sands and gravels, and reference has already been made to them, but the heavier " boulder clay," which is indeed clay in the ordinary sense, has the same soil-forming properties as clays as a whole, which we shall now consider.

Clays are either superficial deposits—drifts, as they are also called—of widespread or local distribution overlying older rocks (such is the case of alluvial and glacial clays) or they are part of the " solid " geology, forming beds of rock which belong to the sedimentary series which is shewn in Appendix II, p. 280).

Clay is an impervious rock. Its substance is porous and normally it holds a great deal of water constantly in its pores; nevertheless water cannot pass through beds of clay. Clay is plastic, but in and below the soil proper, roots of plants instead of penetrating into the actual substance of the clay, pass only through the spaces which separate the numerous structural units into which a clayey soil is naturally split up, and spread their rootlets over the surface of the individual soil aggregates: crumbs, granules, clods, prisms and so on (see section on Soil Structure, p. 257.)

It is from the surface parts of the clay rock with its structural units already in being that a soil is gradually developed. Plants must make use of the cracks or fissures in the rock and develop them into a system for their own support. Two typical covers of clay in Great Britain are oak wood and grass; in the former instance, which is really the more natural, because this country is in the forest belt of the temperate zone, the deep roots of the trees are thrust far down into the clay, while in the case of grass the matted roots of the turf are woven into the comparatively finely-divided units of a limited surface soil. Thus while well developed soils on the clay are naturally

shallow, the material is pliable enough to allow of the deep penetration of tree-roots between the structural units of the clay at some distance from the surface. In both cases the vegetation, whether grass or forest tree, may be presumed to accentuate and help to develop the natural tendency of the clay to form granules, prisms and other structures, so that there is a close correspondence between the type of plant growing on the clay and the structure that the soil exhibits.

The whole series of igneous, sedimentary and metamorphic rocks provides, as we have seen, a wide range of raw materials for the production of soils, and the characteristics of those materials tend to impress themselves upon the resulting soils in two ways. First there is the chemical influence of certain substances found in the original rocks, notably calcium carbonate, which if it is present is likely to produce an alkaline soil. Secondly, the particle size which characterizes the parent rock or the products of its disintegration is found reflected in the texture of the soil that eventually emerges from the weathering processes.

CONVERSION INTO SOIL.

The raw materials destined to produce true soils, but not yet converted into them, are termed skeleton soils, and it is a good term because the mineral matter derived from rocks serves as a skeleton upon which, by the addition of humus, are built up the features which are recognized as those of fully developed soils. Whether the rock be a hard one, like granite, or loose and unconsolidated, like a glacial sand, the processes of conversion into soil are weathering processes, and so to these processes we must naturally give careful consideration. But before passing on to this part of the subject,

we may with advantage give brief attention to three constituents of the soil: humus, water and air.

NO MERE MIXTURE.

No bullock is a mere mixture of bones and brain and blood and beef, nor is that other natural object, the good soil, a mere mixture of mineral matter, humus, air and water. Nevertheless, in the soil these four things are woven together into an intimate inter-relationship by a long and complicated series of weathering processes, and it helps us to understand the soil if we study the humus, at least as much as it helps us to understand the bullock by studying the anatomy of his brain.

HUMUS.

The Humus in the soil is its organic fraction, the sum of the substances which owe their presence there to the activities of animals and plants. The great American exponent of humus, Selman A. Waksman, in his book *Humus* gathers up some definitions upon which the following is based: Humus is a natural, complex, colloidal aggregate of dark-coloured, amorphous substances, originating from decomposition of animal and plant residues by micro-organisms. Chemically humus includes constituents of plants resistant to decomposition, organic substances undergoing decomposition by hydrolysis, oxidation or reduction; and compounds built up by micro-organisms.

Speaking generally, humus has, among others, the following effects upon soils:—

(1) It provides nitrogenous food, which, being absorbed by plant roots, helps to build up the vegetative structures of the plant.

(2) It provides food for bacteria and fungi, and a medium in which they can work.

(3) By the action of bacteria it liberates carbon dioxide which increases the solvent power of soil water (both these points are dealt with elsewhere in this book, see pp. 18 and 82).

(4) It changes the texture of the soil; its colloidal constituents act like clay.

(5) It holds moisture and so conserves water for the use of the plant.

(6) It gives a darker colour to those horizons of the soil of which it is an important component.

The following figures for humus in different soils are cited by Waksman in *Humus*. They are indicative of the fact that the distribution of humus is different in the soils in the different great soil groups of the world.

HUMUS CONTENT OF SOME RUSSIAN SOILS.

Podzol

Horizon	Humus per cent.
A_1	3·64
A_2	0·37
B_2	0·10
C_1	0·22

Chernozems

(1) Loamy: A	11·04
(2) Clayey: A	9·88
(3) Clayey: A	15·64

Chestnut Soil

A_1	2·01
A_2	1·11
B	0·84

Although the proportion of humus to the other constituents of the soil is frequently not high if we take the whole depth of the soil down to the rock, nevertheless it is a very important part of the soil, and while it is here dismissed in comparatively few words reference to its presence and work will be found repeatedly in later pages of this book.

WATER AND AIR. Water and air seem such commonplace things that there is a danger of forgetting that they are both important constituents of the soil.

In the production of the soil and its extension in depth, water is both directly and indirectly an agent of weathering (see Chapter V on " Weathering," pp. 70–95).

In maintaining the natural functions of the soil, water acts as a solvent for plant foods found in the soil and, as a result, roots are able to take from the soil substances which are needed for the growth of vegetation.

But while water in moderation is thus necessary for the well-being of plants, water-logging of the soil has an inimical effect upon all but the few that are especially adapted to live with submerged roots. Other effects are that the exclusion of air enables anaerobic bacteria to flourish and that iron compounds become reduced to the ferrous state.

Where the water recedes and leaves spaces between the minute particles of the soil, air comes in. From the fact that about one-fifth of the air is oxygen, the oxidizing effect of air is considerable, and this again is a matter dealt with under Weathering, p. 78. Also many soil bacteria need air, and their work is only possible when oxygen can get into the soil spaces.

The inter-relation of water and air in the soil is well illustrated by a catastrophe which may over-

take fruit trees: apple, pear, plum, cherry, raspberry, loganberry, blackberry, or gooseberry. They die from the suffocation of their roots by water-logging in two distinct ways, which have been investigated by B. S. Furneaux and W. G. Kent. In the one

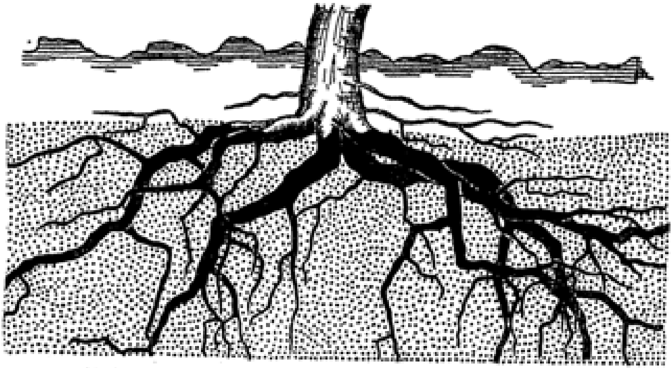


Figure 14. Effects of Water-Logging.
Here is one tree of many in a poorly-drained soil. Roots shewn in black are dead and blackened. Soil exhibiting orange-brown and bluish mottlings, the evidences of water-logging, is represented by dots. Well-drained and well-aerated soil is unshaded, except for horizontal lines at the surface. *Drawn by Basil S. Furneaux.*

instance those roots die which, irrespective of the geological material, become water-logged, as for example in a shallow heavy soil over clay, during a wet season. If the water-logging does not extend to the surface the unaffected roots, those to which the air supply is maintained, may be vigorous enough subsequently to re-establish the root system of the tree. In the other case the soil would not be expected from its texture and the conditions of its natural drainage, to suffer from water-logging. Here persistent

rocking of the tree by wind, where the root-hold is weak and the staking poor, causes around the roots a compaction of the soil. The rocking causes a destruction of the soil structure (see page 257) and the soil becomes puddled. This congestion assists retention

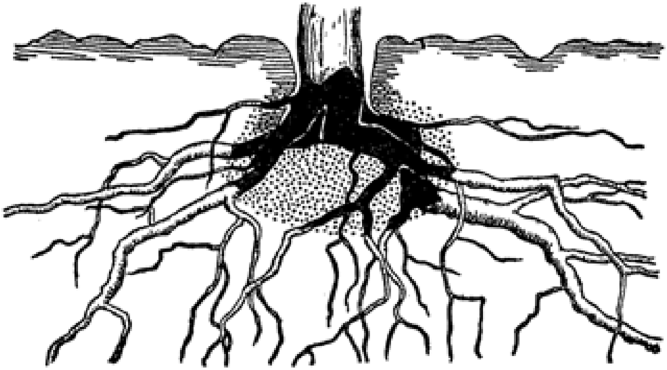


Figure 15. A Tree Killed by Wind-Rocking.
Here is an apple tree in a fairly well-drained soil. The soil round the root has been puddled because the tree has been rocked to and fro by the wind. The roots shewn black are dead and blackened. Soil exhibiting orange-brown and bluish mottlings, the evidences of water-logging, is represented by dots. Well-drained and well-aerated soil is unshaded, except for horizontal lines at the surface.

Drawn by Basil S. Furneaux.

of the moisture and exclusion of the air immediately around the root. All the root tissue in the compacted soil dies though the roots outside the congested area may remain normal and healthy and even throw up suckers. The death of the roots and the base of the stem kills the tree, because it can no longer take in food from the soil.

CHAPTER V

WEATHERING

Hard rocks are broken up and converted into soils by a series of processes we call weathering. Here, in this chapter, these processes are dealt with one by one. In nature the processes generally act, not singly, but in association with one another. After hard rock has been broken down into fine particles and plants have begun to grow in the debris, weathering still goes on in the young soil. It still goes on in a well-developed soil and is continually producing changes. Consequently this subject of weathering is of great interest and importance to the student of the soil.

WEATHERING.

" The words stone and rock have long been used by many peoples to signify durability and stability, but this is not borne out by a closer observation of nature. Peoples dwelling in mountainous regions know the instability of rocks and cliffs, as indeed is shown by the Finnish name for the coarse-grained granite peculiar to that country. It is known as rappakivi—literally, rotten rock. According to the famous geologist Heim, the people in certain parts of Switzerland say of a weak-minded and morally unreliable person that he is as undependable as a cliff. And this is said by people who spend their lives among rocky mountains and observe the disintegration with their own eyes."

—B. B. Polynov, *The Cycle of Weathering*.

PARENT MATERIAL.

THE ultimate source of all the mineral matter in every soil is the crust of the earth. It is hoped that enough

has been said about the different kinds of rock that go to make up that crust to shew that there is great variety in this parent material. Some rocks are compact and hard, many igneous and metamorphic rocks are of this nature; others, especially some sedimentary rocks like clay and soft sandstones, are not hard at all and do not conform to the popular notion of a rock though they are quite correctly called rocks because they fit in with the geological definition of rock, which embraces any material that forms an extensive part of the mineral crust of the earth. Now compare any soil you know with these parent materials of soils, these rocks; the mineral part of the soil may be compact but it can readily be rendered loose and indeed most of the preparation of the soil to receive the seed consists in getting its upper few inches into a loose and friable condition. Among rocks there are many that resemble soil in easily being rendered loose and friable, sands and soft sandstones, many glacial deposits, alluvium and brick-earth are good examples, while clay is a soft and plastic rock. These rocks will readily contribute their mineral constituents to the formation of soil because those constituents are in a condition readily accessible to roots, but before a hard rock like a compact sandstone or a granite can be converted into the mineral part of a soil it must be broken down and rendered in some way or other friable and loose. The process by which this is brought about is termed weathering, and because it is a natural process of the greatest interest and importance in understanding the development of soils it must be carefully considered.

The Agents of Weathering.

In the discussion of weathering it is usual to describe and explain a number of agencies by which the process

as a whole is accomplished in nature. There is a danger in this; the danger is that we should come to regard these natural agents as independent of one another, working alone, producing effects which can be isolated and studied without reference to other phenomena. To be forewarned is to be forearmed. These so-called agents of weathering do not act independently, rather they work in groups or batteries and it is the sum of their actions and inter-actions that produces the result in which we as pedologists are really interested. Weathering, while it results in the disintegration of rocks, plays a constructive part as far as the soil is concerned, because it produces much of the raw material for soil formation.

THE DIFFERENT KINDS OF WEATHERING AGENTS.

In the case of some of the agents of weathering their work results in the comminution of the rock without the production of any new substances; it has a similar effect to that which would be brought about by breaking up the rock with a hammer or crushing it under a great weight. Such agents are physical. In contrast with these some weathering agents produce new substances which were not present in the original rock. Such agents are chemical. And then, side by side with the chemical and physical agencies we may recognize a third group which we may call the biological agents of weathering; these are animals, plants and microbes.

An Enumeration of Weathering Agents.

Before we deal with some important agents concerned with weathering it may be convenient to the reader if we name the agencies to be discussed; they are as follows:—

I. Physical Agents.

(1) Alternate wetting and drying.
(2) Frost-action.
(3) Alternate heating and cooling.
(4) Solution.
(5) Sand-blast.

II. Chemical Agents.

(6) Hydration.
(7) Hydrolysis.
(8) Oxidation.
(9) Reduction.
(10) Carbonation.

III. Living Agents.

(11) Animals.
(12) Plants.
(13) Micro-organisms.

The division of these agents into three groups is somewhat arbitrary and certainly must not be regarded as absolute. For example, plants produce substances which in their turn have a chemical weathering effect; again, in hydration, new chemical substances produced have a greater volume than the original mineral so that expansion, which we may regard as physical, is an important feature of hydration. Again we emphasize the point that in nature it is an exception for one agent of weathering to act alone; it is usual for a number of agents to act together, so that it is sometimes difficult to separate the individual causes of a complex result.

The Agents of Weathering.

Some natural substances increase considerably in volume when they are wetted and shrink again when

they dry. Our best example of this is clay. In dry weather maximum shrinkage in clay is established and if a clay is examined in the field after a long period of rainless weather it will be found that there are many cracks in the ground, and the clay itself has been divided up into characteristic prisms, while granules have been produced amongst the roots of the turf. Prisms and granules owe their form to the repeated shrinkages and re-expansions which accompany dry and wet weather respectively. Another good example of the importance of alternation of moisture conditions in weathering is afforded by the case of shale. Shale is a lamellar rock, that is to say, it is made up of a series of thin plates like the leaves of a book and under conditions of alternate wetting and drying these tend to loosen and eventually to break up.

ALTERNATE WETTING AND DRYING.

It is a well-known fact that frost, the freezing of water, causes the disintegration of exposed portions of rock. Where crevices, great or small, are filled with water before freezing takes place, the actual change of the water from the liquid to the solid state is accompanied by the exertion of an enormous force whereby great masses of rock may suffer cleavage and be broken off, and, of course, smaller fragments may be split off in the same way. The exertion of this enormous force is due to the fact that when water freezes it expands about one-eleventh of its volume or bulk. Not only are fragments of rock split off by the frost, there is also a pulverizing effect in certain cases. Thus water, having been absorbed into the actual substance of porous rocks or of soils, lies there in the pores of the material, so that as soon

FROST-ACTION.

as freezing takes place the same enormous disruptive force is brought into play, and the rock may crumble into powder. In the case of soil, a fine tilth, or powdery state of the earth, is produced in this way.

ALTERNATE HEATING AND COOLING.

Disintegration of rock may be brought about by change of temperature alone. When a rock is exposed to the heat of direct rays of the sun the temperature of its outermost layer rises and it expands. When the sun's rays cease to act the rock cools and contracts. Both these processes tend to set up strains in the rock which lead to the splitting off of fragments from the exposed surfaces. Under certain circumstances changes of temperature alone are sufficient to account for much disintegration, even when the rock is homogeneous. Weathering is more marked still where the rock is made up of a number of different minerals with different coefficients of expansion (i.e. they expand to different extents with the same amount of heating) because in such a case strains are set up between particle and particle within the rock and this adds to the likelihood of disintegration occurring.

SOLUTION.

The solvent action of water plays an important part in weathering, but water in nature is never quite pure and when carbon dioxide is dissolved in it its solvent power is greatly increased. Although it is thus practically impossible to consider separately the action of pure water and of water containing dissolved impurities we are here at the moment thinking only of pure water, and water containing very small quantities of other substances in solution and we shall deal later with the solvent effects of water richly charged with carbon dioxide. All mineral substances are more or less soluble in water and thus

the surface of rocks is gradually removed in solution by the rain which falls upon it. Water that penetrates into the substance of rocks removes part of it. Of course, there is a great range of solubility among minerals while some like common salt are very soluble, others at the other end of the scale, such as quartz, are not readily dissolved, and a whole series could be listed to fill in the gap between these two. When we have studied the subject of soil formation it will be appreciated that the weathering effect of solution plays an important part in maturing a soil, for by this means various substances are carried up and down in the soil. It is true, then, that solution aids the disintegration of rocks by removing some substances and thereby causing structural weakness and also that it is responsible for soil forming and soil maturing processes because it is the means by which many substances are moved from point to point in the body of a soil. Movement of this kind in a soil is frequently termed translocation.

SAND-BLAST.

Especially in deserts, sand-laden wind etches the rocks and thus breaks up their substance, the same agent plays a lesser part wherever gritty particles are carried by the wind.

HYDRATION.

Hydration is chemical union of water with a substance so that a new compound is produced. It is a very common process in nature, and as an increase in volume or bulk occurs when hydration takes place, it is a very important disruptive process. Thus the expansion may cause splitting or pulverization of rock as well as change of composition in its constituent minerals.

The slaking of quicklime is so well-known that it is perhaps best to use it as an example of hydration,

although the process in this simple form does not actually occur in nature.

When water is added to quicklime it combines with it (an oxide, oxide of calcium) to form slaked (hydrated) lime, a hydroxide, thus:—

$$\begin{array}{c} CaO + H_2O = Ca(OH)_2 \\ \text{Quicklime} + \text{Water} = \text{Slaked lime.} \end{array}$$

and this is accompanied by the evolution of heat and an increase in the volume of the solid substance present.

In nature there occur hydrations of the mineral hematite (sesquioxide of iron, Fe_2O_3), these hydrations form a series of minerals to which special names are given according to the amount of water that has been taken up. The best known of these minerals is limonite ($2Fe_2O_3.3H_2O$).

HYDROLYSIS.

Hydrolysis is the dissociation of a strong base and the radicle of a weak acid in the presence of water. It results in the disintegration of rocks where the minerals concerned form a part of the crust of the earth.

A common, somewhat complex mineral that is subject to hydrolysis in nature is orthoclase, one of the felspars. When orthoclase felspar is decomposed, a mineral that is produced is Kaolinite, a fundamental constituent of china clay. The case is worth considering in some detail.

The chemical composition of orthoclase may be written:—

$$K_2O.Al_2O_3.6SiO_2.$$

This, of course, means that potassium, aluminium, silicon and oxygen all occur in this chemical compound (which is a crystalline mineral) in the proportions

in which they are present in potash (K_2O), alumina (Al_2O_3) and silica (SiO_2). Potash, alumina and silica are all oxides. Silica combined with hydrogen forms a weak acid known as silicic acid and when (as in orthoclase) other substances called bases occur combined with silica in the place of the hydrogen the compound that results is called a silicate. Here then, in orthoclase, we have a potash-alumina silicate.

When hydrolysis of orthoclase takes place in nature the silica is dissociated from the bases of alumina and potash in the presence of water. There is always, in the natural conditions under which this hydrolysis occurs, an excess of water, and both the potash and some of the silica are removed in solution. Hydration of the remaining silica and the alumina takes place, and kaolinite is produced thus:—

$$Al_2O_3+2SiO_2+2H_2O=Al_2O_32SiO_2.2H_2O$$
$$\text{Alumina}+\text{Silica}+\text{Water}=\text{Kaolinite.}$$

OXIDATION.

Since the rocks are, at their surface, always in contact with the air there is every opportunity for the oxygen of the atmosphere to combine with minerals and mineral substances. This is the process called oxidation. The atmosphere penetrates into every crevice and fissure of rock and soil, and this brings the air into more intimate contact with the different substances present and gives greater opportunity for oxidation. Experience shows that moisture aids in the process, and this is generally present in adequate amounts in the air and in the soil. Rainwater takes oxygen into solution from the atmosphere and carries it down into joints and pores of rocks, and so a still closer relationship is established between oxygen and mineral. As a matter of fact, water and dissolved

atmospheric oxygen are closely associated in many of the instances of oxidation and often a series of reactions is involved of which oxidation is only one. This emphasizes the fact that weathering agents rarely act singly.

A good instance of oxidation in nature is that by which ferrous carbonate ($FeCO_3$) is converted into limonite ($2Fe_2O_3.3H_2O$), and it is an instance in which oxidation merely plays its part as one link in a chain of weathering processes.

While oxidation may be taken to mean the chemical addition of oxygen, reduction is the removal of oxygen from a compound. In water-logged places such as areas of riverside soils, especially when there are quantities of decaying vegetation, oxygen is excluded from contact with the underlying rocks. The decaying vegetation may be said to be "oxygen-hungry," using up dissolved atmospheric oxygen and any oxygen obtainable from mineral substances that happen to be present. This chemical removal of oxygen sometimes has a disintegrating effect, and so is enumerated as one of the agents of weathering.

REDUCTION.

Carbonation is the effect of carbon dioxide dissolved in water upon the substance of rocks and soils. Carbon dioxide is one of the products of decomposing plants and is readily taken up by rainwater as it passes through the uppermost part of the soil.

CARBONATION.

Carbonated water, i.e. water impregnated with carbon dioxide, has an enhanced solvent effect upon some rocks, especially limestones, and upon some of the substances which act as cements in such sedimentary rocks as sandstones. The removal of the cements which hold the tiny particles of sand together causes the disintegration of the sandstone.

When carbonated water acts upon a rock containing iron compounds, either as cements or as constituent particles, ferrous carbonate is frequently formed. It has already been pointed out when speaking of oxidation that this ferrous carbonate is converted upon oxidation into limonite. All these links that have been mentioned play their part in the complex of weathering. All tend to cause the disintegration of rocks and all aid in soil formation.

Anything that, by disturbing the soil, lets air and rain in, aids in the processes of weathering. Oxygen, and water with the substances dissolved in it, thus reach parts of the soil or rock that would otherwise remain unaffected. It is in this way that many animals, both vertebrate and invertebrate, promote the disintegration of rocks and the development of soils. Rabbits, by burrowing into the ground, help in the destruction of soft rocks; foxes, badgers, moles, rats, mice, and other mammals do the same kind of work, while the waste products of living, and the bodies of dead, animals provide substances which have a chemical action upon minerals which, in turn, aids decay. Charles Darwin focussed attention upon the importance of the activity of earthworms. Their burrows extend deep into the ground, sometimes for several feet, and the amount of soil that they turn out upon the surface is very considerable. Many insects live the whole or a part of their life in the soil, and their normal activities disturb it; the larvæ of beetles such as chafer-grubs and wireworms, the larvæ of flies and all stages in the life history of some ants are examples. Then there are other arthropods including centipedes, wood-lice and millipedes, these too disturb the soil.

ANIMALS.

And so it is, that whether animals merely move

about in the surface soil or turn over vast quantities of earth and so expose fresh material brought up from below, they all help in the decomposition of the rocks.

The roots of plants, as they grow, penetrate joints and crevices in rocks and soils; the larger roots as they increase in diameter exert an increasing disruptive force, and in this way hard rocks may be split and broken up. In the surface soil, as can easily be seen by examining the turf of pasture fields, plant roots may form a sponge-like mass, which conserves moisture and provides innumerablestrands to separate soil particles, so that air and moisture can find their way in. Some roots go down a long way into the ground and their work may therefore extend to a depth of many feet. I have previously mentioned, page 28, seeing the roots of chestnut going down into friable sandstone rock for more than forty feet; the cutting back of the face of rock in a sandpit was encroaching upon an established chestnut coppice, and so the roots came to be exposed in the pit face. Roots, in their search for food, produce acids which have a solvent action, particularly upon carbonates, so that a root running in a crevice in limestone or marble will sometimes etch a pattern of itself upon the walls of the fissure by dissolving the part of the rock with which it comes into contact.

PLANTS.

When plants die and when leaves and other organs fall, the debris that is left gradually decomposes, and, among the products of decay, carbon dioxide is of great importance because it is capable of giving an acid reaction to any water in which it becomes dissolved. Rainwater percolating through the upper part of the soil frequently becomes charged with carbon dioxide in this way, and very important soil-

forming processes (which are also weathering processes as far as the rock is concerned) are carried out by the solution. Thus, alive or dead, plants and their parts constantly aid in the decay of rock and the building of soil.

The fungi are a group of lowly plants to which the familiar mushroom and the many different kinds of moulds belong. Among fungi there are some that are widespread in soil which live readily upon decaying plant debris. In this way, they break down the dead remains of plants into simpler substances. When circumstances are favourable for them, their work results in the decay of large quantities of such materials as the leaves of trees. In forests and woods, where there is a great fall of leaves every year, this work is very important.

BACTERIA.

Bacteria, or microbes as they are sometimes popularly called, are minute living bodies so small that a very powerful microscope is necessary to see them. There are, of course, very many different kinds of bacteria. Some kinds cause diseases in human beings, in animals, and in plants, but others, from the work they do, are definitely beneficial to man. Many different kinds of beneficial bacteria occur in the soil, they can be found on the surface of soil particles, in channels between soil particles and in nodules occurring on the roots of legumes, as well as in the masses of decaying vegetation which are frequently a part of the surface soil. Bacteria play a major part in the destruction of the waste products and bodily remains of animals and plants. They produce from highly complicated chemical compounds, which are characteristic of the bodies of all living things, much simpler substances. A good example of a simple substance made by bacteria in this way is the

gas called carbon dioxide (CO_2). It has already been made clear that carbon dioxide is most important in promoting rock decay and mineral disintegration,

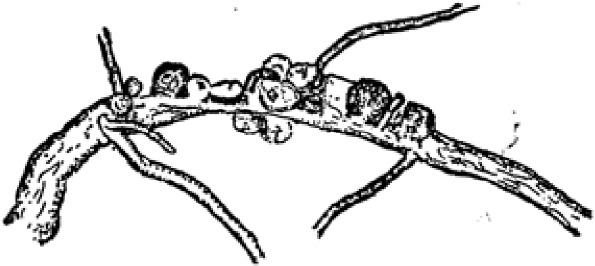


Figure 16. Nitrogen-fixing Bacteria.
Nodules on Broad Bean root. One-and-a-half times natural size.
Drawn by S.G.B.-B.

and the significance of this liberation of the gas by bacterial action will therefore be fully apparent.

Again, bacteria have a great influence upon soil fertility, and so, at least indirectly, by promoting plant-growth, have an effect upon weathering. Among soil bacteria none perhaps are more surprising in their work nor more interesting to consider than those which have the remarkable power of taking the gas nitrogen from the air and fixing it. By this is meant that the nitrogen from the atmosphere is taken and combined chemically with other elements to produce substances which can be used as food by the plant. Plants need substances containing nitrogen for the building up of their tissues, and although the leaves and stem of a plant are in continuous contact with nitrogen which forms four-fifths of the atmosphere, they are quite unable to

make any use of it directly. It can only reach the plant through the soil and then in the form of chemical compounds (nitrates). Thus bacteria in the soil that can fix atmospheric nitrogen are of great benefit to plants. In addition to bacteria living free in the soil that can do this work, there are others which form nodules on the roots of leguminous plants,

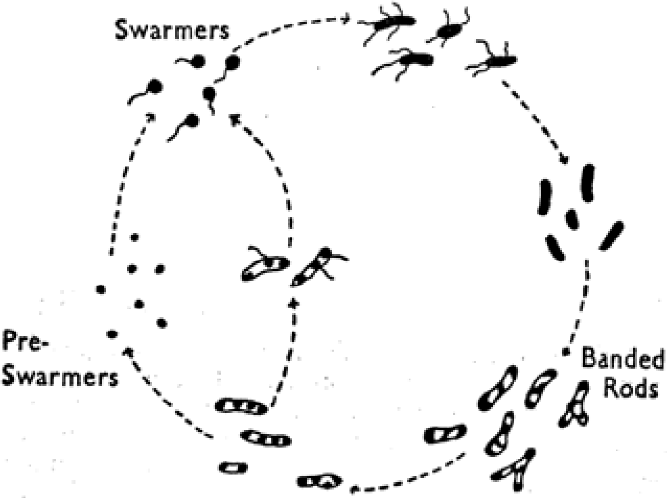


Figure 17. Life Cycle of the Nodule Organism.
Very highly magnified. *Drawn by Dr. H. G. Thornton, F.R.S.*

such as clovers, peas and beans. In these nodules great colonies of nitrogen-fixing bacteria live and carry out their important work. There are bacteria (and fungi) which live upon nitrogenous substances in soil and eventually produce ammonium compounds which become available as plant food. There are also bacteria in soil which similarly produce other nitrogenous plant foods: their final forms, those available

to the plant, are various nitrates. Again, there are certain bacteria which have the power of using iron compounds found in solution in soil-water to form less soluble, and therefore more permanent, substances which may be deposited in the soil. There are other bacteria, again, that deal with compounds of sulphur in a similar way. Though we may not know the exact details of how all these results are brought about, the substances formed are obvious enough, and there is a clear association between the soil conditions which are favourable to certain bacteria and the characteristic chemical substances that are found in the soil under those conditions.

Weathering in Relation to Climate.

We have passed in brief review some of the principal agents that cause weathering. From what has been said it will be clear that all these agents are not in all places of equal importance. In some parts of the world, for instance, frost is frequent, in other places it is unknown. Alternate heating and cooling of rocks is very important in hot desert regions, less important in temperate regions where the daily range of temperature is less and there is less direct exposure of the rocks to alternations of temperature. Vegetation is different under different climatic conditions, and this means that the nature and quantity of plant debris present (upon which weathering in part depends) are also, to some extent, governed by climatic factors.

CLIMATE AND WEATHERING.

The climatic pattern of the world is a pattern of heat and cold, moisture and dryness; so also are the patterns of vegetation, weathering and soil-distribution. Like many other matters of pedological interest, the relationship between

Figure 18. The World-Pattern of Climate.

CLIMATES OF THE WORLD

The map on these two pages indicates the broad distribution of the climates of the world. There are close inter-relationships between soils, climates and vegetation which are revealed by a comparison of three maps given in this chapter.
Some climates like those of deserts very clearly determine the nature of the soil; in other cases the influence of climate is less obvious, but nevertheless very real.

Figure 18a.

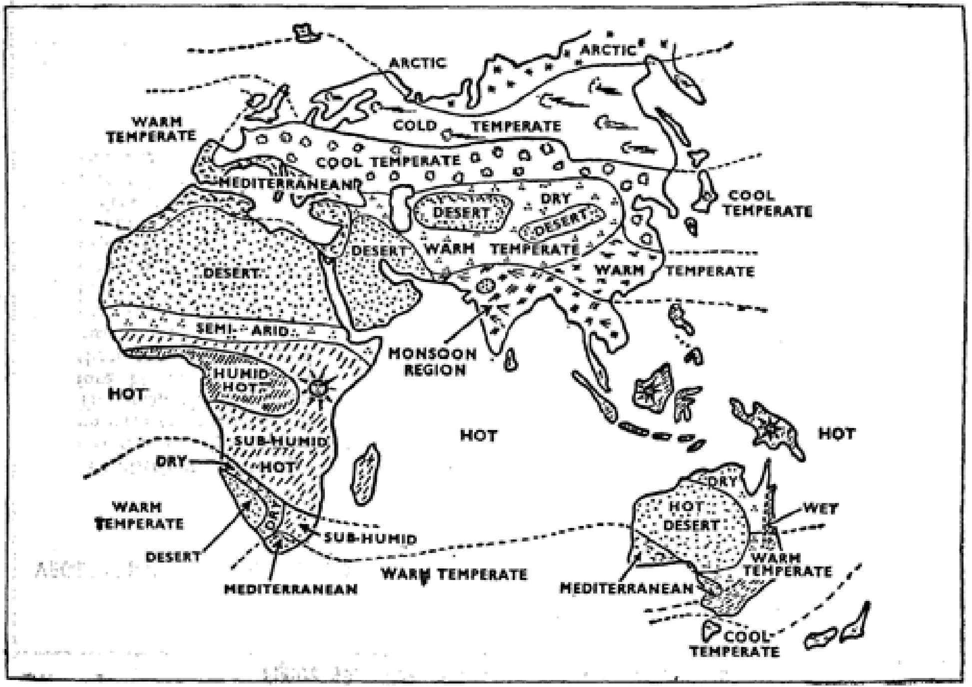

ARCTIC
ARCTIC
WARM TEMPERATE
COLD
TEMPERATE
COOL TEMPERATE
MEDITERRANEAN
COOL TEMPERATE
DRY
DESERT
DESERT
DESERT
WARM
TEMPERATE
WARM
TEMPERATE
DESERT
SEMI-ARID
MONSOON REGION
HUMID HOT
HOT
SUB-HUMID
HOT
HOT
HOT
DRY
WARM TEMPERATE
SUB-HUMID
DESERT
MEDITERRANEAN
WARM TEMPERATE
DRY
HOT DESERT
WET
WARM TEMPERATE
MEDITERRANEAN
COOL TEMPERATE

Figure 19. The World-Pattern of Vegetation.

VEGETATION OF THE WORLD

The distribution of vegetation is clearly wrapped up with climate and soil. This map should therefore be compared with those shewing the world distribution of great soil-groups, and the "world-pattern" of climate. Such maps as these can do no more than exhibit trends and broad outlines but are sufficient to indicate the close relationships of soils, climates and vegetation.

Figure 19a.

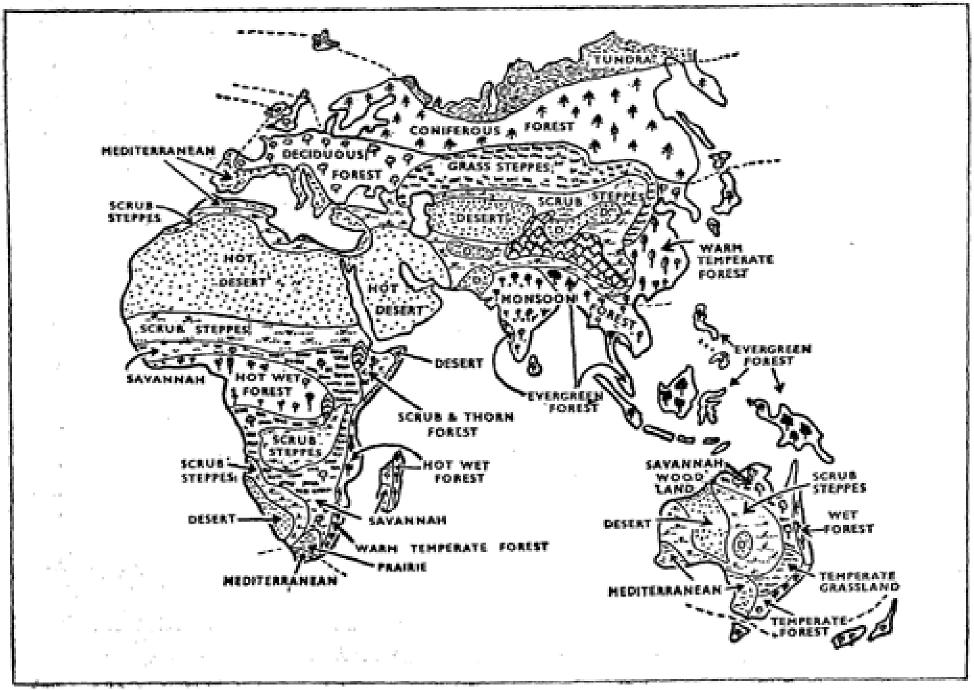

TUNDRA
CONIFEROUS FOREST
DECIDUOUS FOREST
GRASS STEPPES
SCRUB STEPPES
DESERT
MEDITERRANEAN
SCRUB STEPPES
WARM TEMPERATE FOREST
HOT DESERT
HOT DESERT
MONSOON FOREST
SCRUB STEPPES
EVERGREEN FOREST
DESERT
SAVANNAH
HOT WET FOREST
EVERGREEN FOREST
SCRUB & THORN FOREST
SCRUB STEPPES
HOT WET FOREST
SCRUB STEPPES
SAVANNAH WOOD LAND
SCRUB STEPPES
WET FOREST
DESERT
SAVANNAH
DESERT
WARM TEMPERATE FOREST
PRAIRIE
MEDITERRANEAN
TEMPERATE GRASSLAND
MEDITERRANEAN
TEMPERATE FOREST

Figure 20. **Distribution of Great Soil Groups.**

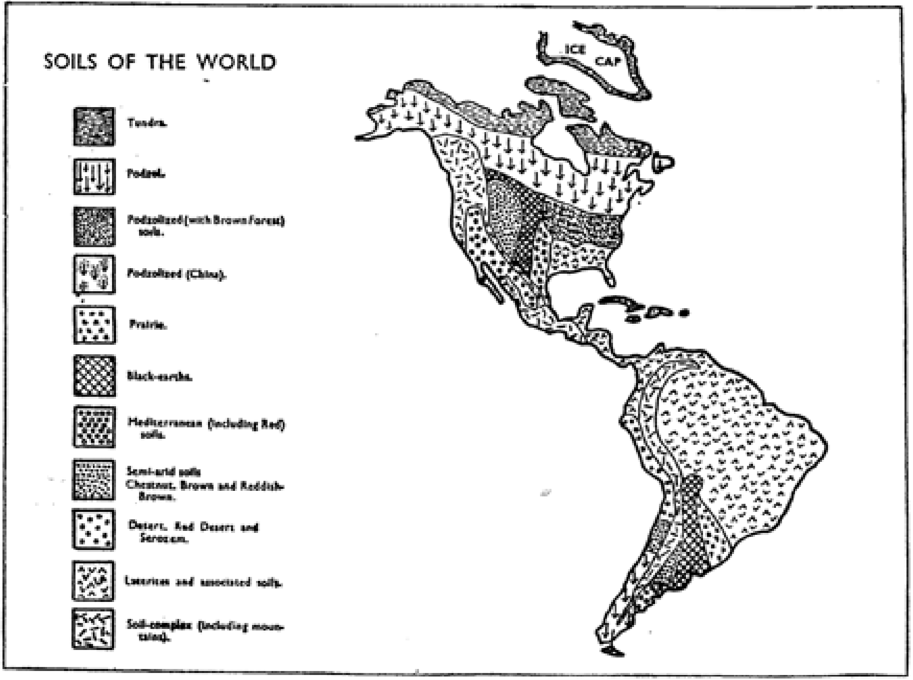


Figure 20a.

climate and weathering is very complicated, but the result of the weathering of rocks is the formation of soil and a comparison of three maps of the world showing climates, vegetation and soil-groups will demonstrate clearly that there is similarity in the patterns exhibited by these three on a world scale.

PLANTS BEGIN TO GROW.

Weathering processes, as a whole, result in the production of a quantity of comminuted material, loose and unconsolidated, sometimes the quantity is small but often it is very large. As we have seen, some rocks themselves consist of comminuted substances, and in such cases no weathering is necessary to give plants a hold in which to begin to turn such a geological deposit into soil. However, by one means or another, comminuted material is produced and as soon as plants begin to grow in it, and however lowly the plant may be, the " skeleton soil," as it is termed, begins to be converted into true soil. It would be difficult to think of a better example than that (cited on page 61) of the growth of farm crops in an English loessal brick-earth. The rock in this case, in its natural state of finely-divided particles, contains the mineral foods that the plants need, and they are present in a form readily available to their roots. Suppose the crop to be peas or clover. The seed sown by the farmer germinates, the roots grow down, the foliage shoots up, nitrogenous food is provided by the bacteria of the root-nodules (see page 83). Upon the death of any of the plant tissues they are added to the mineral constituents of the soil and there then begins an accumulation of organic matter which will provide useful food for following crops. As rains fall some of the clay particles, tiny as they are, and some of the humus (organic matter) from the upper few inches are carried down deeper

into the ground. Some of the oxides of aluminium and iron are taken down by the water, especially when it has had its solvent properties re-enforced by carbon dioxide from the decay of plant tissues.

TRANSLOCATION.

This removal of clay, humus and oxides of iron and aluminium by water (frequently termed "translocation,") is very characteristic of the formation of soil. The substances that are washed downwards by rainwater from the superficial layers are eventually deposited deeper underfoot, perhaps eighteen inches

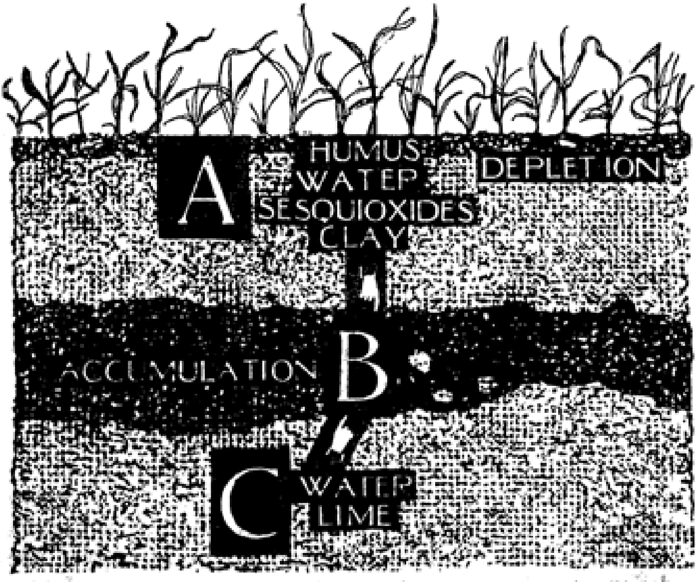


Figure 21. Translocation.

B horizons are horizons of illuviation (accumulation) to which humus, sesquioxides and clay may descend from the horizons of eluviation (depletion) or to which "lime" may come from below.

Drawn by S.G.B.-B.

or more below the surface of the ground. All this means that as the soil develops, it will begin to show visible differences which we can see for ourselves in section in the wall of any excavation we may happen to make. Near the top, the soil will be darker, because it contains decaying and decayed plant debris; below that will come a layer (or horizon, as we should more properly term it) depleted of some of its colouring matter, colouring matter that generally consists of compounds of iron, so that, owing to this loss, it now has a more or less greyish tinge. Going still deeper we shall find the soil containing more clay than in the horizons above, and perhaps one horizon darker, from its accumulated translocated humus, and another redder, from the presence of hydrated oxide of iron derived in part from the horizons above. In the changes that produce soil from mineral detritus, some at least of the processes, by which rock is reduced to a condition of more or less finely-divided debris, can be recognized. It is evident that in pedogenesis (the formation of soil) we have a continuation of rock-weathering and that, in this sense, it is true that soil is weathered rock.

PEDOGENESIS.

The course of events that we have briefly sketched to illustrate the way in which soil is formed from rocks is quite a usual mode of pedogenesis in temperate climates, but where temperatures are higher or lower and rainfall lighter or heavier and where vegetation is different or where special chemico-geological factors are involved, the processes, though comparable, are different. They are discussed in the section of this book dealing with the great soil groups of the world (pp. 211 to 242).

Having traced the story of the good soil from those remote days when the earth's crust first cooled,

along all the lines of preparation which precede and include pedogenesis, through processes of comminution, weathering and translocation to a wonderful product, we must now leave the true soil in its fully developed state and return to the farmer who is naturally anxious to make the best possible use of the soils that occur on his own farm.

Figure 22. Ploughing in the Middle Ages.
After Larking (original source, Cotton MSS. Tiberius B. v., pt. 1, fol. 3, 11th century. British Museum).

CHAPTER VI

THE GOOD SOIL AND THE FARMER

The farmer who wants to know all about his own soils should begin by recognizing their differences accurately. You cannot fully recognize differences between two soils unless you take proper account of their outstanding properties and this chapter indicates what these are. This assessment of the properties of individual soils is useful in other ways; it helps us, for example, to get an idea about some of the capabilities of a soil.

THE FARMER HIMSELF.

YOU will remember that we dwelt at the beginning of Chapter II upon the antiquity of the farmer's craft. His work has been continuous from prehistoric times, and the picture of our Anglo-Saxon or Norman ancestors ploughing, differs but little from our conception of the same operation in the earlier part of the nineteenth century. Having pointed out that the soil, which the husbandman has cultivated so long and so industriously, is a natural object with natural properties, some of which were enumerated, we turned to the farmer himself to find that his own observations and his experience fitted in with the view that the pedologist or soil scientist takes of the soil nowadays. We touched upon the fact that in modern soil science we have an extension of the farmer's own method of regarding the soil, a systematization and elaboration of the knowledge

gained from experience by farmers as a whole over a very wide area, so that that kind of knowledge might be available for everybody who desired it as an aid to good farming, in whatever part of the country they might happen to live and work.

DIFFERENT SOILS.

The intelligent farmer knows a good deal about the differences which there may be between different soils on different fields or even, sometimes, in the same field, on his farm. In the case of land that has been cultivated by the same family for a period of years a considerable body of information is likely to accumulate almost imperceptibly about the capabilities of the different soils, their suitability for certain crops, their response to the use of lime, their manurial needs and the best use of implements. All this information is usually gained as the result of personal or family experience, and if the farmer moves to another part of the country or even to another farm in the same neighbourhood, that experience is lost and the building up of new information about newly acquired land becomes necessary.

OFFICIAL INFORMATION.

In many of the States of the United States of America there is a wealth of detailed official information of the kind which the farmer in England learns from his own experience about his own land. This information is available about all the soils in the State, so that it is possible to tell any newcomer to a farm which is the crop best suited to any particular soil or to direct a stranger to a vacant farm or a district where he will find soils capable of growing the crop he wishes to cultivate. Unfortunately, we have not yet reached this stage in Great Britain, but as soil-survey work continues and as soil utilization services come into fuller activity it will be just as possible

here as in America to provide any farmer with this very desirable type of information.

OUR GREAT-GRANDFATHERS.

Again, if we read old agricultural books we find how nearly the modern systematic knowledge of the soil was reached eighty years, a hundred years or more, ago, and yet something prevented the realization of some essential point in the systematization of knowledge which would have enabled our great-grandfathers to have made a great deal of progress towards a detailed classification of the soil so that full, and the best, use could be made—as is possible in the United States to-day—of every soil on every farm. Here is an example; it is taken from the article "Soil" in Morton's *Cyclopedia of Agriculture* (1855): ". . . the arrangement of soils into classes is of practical utility, inasmuch as it enables us in a great measure to dispense with local and general terms, such as hazel-loam, fat-soil, brown-loam, clayey-loam, humus-soil, garden-mould, and other terms, to which different meanings are attached in different parts of the country, and to substitute for them terms admitting of distinct definition. It is owing to an indefiniteness of this kind, as is well known, that a great deal of our local agricultural literature is utterly useless to the general reader." In the same article we have reference to water conditions in soils and other matters which to-day are recognized as being of great importance: "Another important property, which influences the agricultural capabilities of soils, is their power of holding water. Some soils will drink in and retain a much larger proportion of rain falling upon them than others, before the rain percolates into the subsoil; and it is evident that in dry climates this property must render a soil more valuable. . . .

"Again those soils which hold the largest amount of water, also retain it with the greatest pertinacity —another property which accounts partially for the dissimilarity in the fertilizing characters of soils. . . .

"The study of the characters of soils, it appears to us, has hitherto been prosecuted too much in a one-sided direction."

It becomes then a question—if the farmer's own notions about the soil and many of the ideas that the old writers had about the soil are found to be so acceptable to modern scientists—as to how concepts are to be reduced to a practical system.

The answer to this question is that, in his work, the pedologist takes as one of his units what he calls the *soil-type*, which is exactly what the farmer means when he speaks of a *soil* on his farm. The farmer recognizes this soil from that, and in a precisely parallel way the pedologist recognizes a certain soil-type in the field, defines it and describes it, so that it can be recognized again, by anyone who understands the terminology properly, wherever that soil may happen to be found.

RECOGNITION.

Strictly speaking, the *soil-type* of the pedologist and soil surveyor (which is also the individual "soil" of the farmer) is the unit of soil-classification, but in practice when studying and classifying soils in the field the scientific observer of to-day seeks to recognize first, not the soil-type, but the *soil-series;* and so, as this book is intended to be a practical book, let us try to understand clearly, first of all, what a *soil-series* is, and afterwards we can speak about individual "soils" or soil-types.

A soil-series is a group of soils that are essentially alike in all the following particulars: (i) Their geology, especially the geology of the parent materials from

which their mineral parts were derived and the geology of the rocks below the soils proper, whether they be the parent materials or not. (ii) The mode of deposition of the mineral parts of the soils; this may be by water, or ice, or wind; or by disintegration *in situ* of some hard rock. (iii) The colour of the soils at

THE SOIL-SERIES.

Name: Wood Symbol: 2 W

Location: Pond Field Date: 24.v.30.

1 Geology : River Terrace
2. Deposition : Water
3. Colour : Brownish gray
4. Topography : Low-lying undulating
5. Drainage : Impeded
6. Profile A : 10" brownish grey loam

B : 11½" { 4" chalky loam
7½" coarsely granular iron-stained chalky drift

C : at 21½" granular chalky drift

7 Reaction : near pH 7.5

Soils Wood Loam (Pond Field), Wood Silty Loam, Wood Silt Loam.
pH 7.3 – 7.5.

Figure 23. A Field Notebook.
A page from a notebook shewing the particulars that are entered in the field. Reaction is sometimes a laboratory determination.

the surface. (iv) The topography under which the soils occur. (v) The *natural* drainage of the soils. (vi) Their soil-profiles. (vii) The chemical reaction of the soils. (viii) The climate which prevails in the place in which the soils occur.

Since each of these eight properties of soils is elevated to a position of great importance in understanding the classification of soils, it will be best to proceed now to take these properties in turn and consider them in a little detail before proceeding further with a consideration of classification.

(I) GEOLOGY OF THE SOIL.

Running a sample of soil through your fingers and looking carefully at it you see there the weathered product of a series of changes (some of them may be very complicated changes involving the formation of new minerals) which have befallen mineral substances originally existing in a molten condition. The mineral constituents before you are probably recognizable to an experienced observer as derivatives of one or more kinds of rock. The rock or rocks which have thus provided the mineral part of your soil are called the parent materials. Such parent materials may belong to any of the three main categories of rock: igneous, sedimentary and metamorphic, and this original source of the mineral matter in your soil may either lie a yard or more—or even only a few inches—below your feet or at some considerable distance from the place where you are looking at its soil.

There are other points of a geological nature which are important in determining the peculiarities of any soil. It is largely upon geological features that natural drainage depends, but that is regarded as a separate property and is dealt with separately. Again soil-texture is in part determined by geological

causes, it is naturally typical of soils derived from sands and sandstones that they are "light," while those from clays are "heavy," but soil-texture does not figure in the determination of the soil-series, and a special section is devoted to it in connection with the recognition of soil-classes and the soil-type (see page 151). In soils, colour, topography, mode of deposition, chemical reaction, and some features of the soil-profile each have some relation to geology, but all these again are separately treated as properties of the soil-series in the following pages. The study of the soil has indeed so many links with geology that a knowledge of that science is a great aid in elucidating some of the problems that the student of the soil meets in his investigations.

When a pedologist speaks of mode of origin he is thinking of the mineral part of the soil, and under this head he seeks to define the way in which the minerals of the original or parent rock have found their way into the soil. Fifty years ago it was usual to distinguish soils as "sedentary soils" and "transported soils," and although we now regard the distinction as inadequate if not misleading, there is, in this terminology, a germ of truth which is useful in considering the mode of origin of soils.

(ii) THE MODE OF ORIGIN OF SOILS: THEIR DEPOSITION.

There are places in Aberdeenshire where the soil immediately overlying the granite contains fragments of the rock and much mineral debris actually derived from the granite. On the Carboniferous Limestone hills of Derbyshire are to be found thin calcareous soils directly overlying the rock and bearing clear evidence of having been produced by the weathering of the limestone. In Cheshire there are sandy soils which are obviously derived, as far as

their mineral contents go, from the Triassic sandstone rock which is found a foot or two below the surface. There are similar soils in Kent derived from the sandy Folkestone Beds upon which they lie. We might multiply examples of this kind, but these are sufficient to shew that sometimes the mineral part of a soil has been directly obtained, on the spot, by weathering from a parent rock still to be seen when we dig down a few feet below the surface. These are sedentary soils, their old name by which they are still known.

The so-called transported soils of the older soil-scientists remain for consideration. The idea behind the term was that the mineral materials in such soils had been brought from parent rocks in another locality and had been deposited in the place where the soils now occur. The case is not so simple as that, because there are a great many geological materials, rocks in the geological sense, which have themselves been formed by deposition, after transport by water, ice and wind. The great deposit of boulder-clay which covers so much of the surface of the northern parts of Great Britain is rock in the geological sense of the term, and it was itself derived from a variety of different kinds of rocks transported by ice during the Glacial Period and deposited at that time in its present situation. Similarly the deposits of brick-earth in S.E. England are largely wind-borne in origin, while great tracts of alluvium around the mouth of the Wash have been laid down by the waters of river and sea.

It is clear that the mode of origin of soils is very largely a geological matter and the way in which we define it in any particular case is a matter of common sense. We may generally say that in mode of origin the soil falls into one of the following classes:

(*a*) Sedentary or formed *in situ*. In such a case there is obviously a very close relationship between the mineral particles of the soil and those of the rock beneath. Here it is certainly correct to describe the rock below as the parent material, but in other cases the true parent material of a soil may be a mass of rock situated many miles from the place where the soil itself occurs.

(*b*) Due to water-action. This may be a geological matter where rivers, or river and sea combined, have laid down a great area of unconsolidated material; this is frequently a mixture of gravel, sand, silt and clay brought along the coast by the sea from the wastage of cliffs and shore-line rocks and mixed with similar materials brought down by the river from the disintegration products of the rocks of the watershed. Geologically the products are called alluvium. From the point of view of soil development the importance of alluvium lies in its unconsolidated nature, so that the soil-forming processes are able to work in a loose medium which has already undergone disintegration and so is readily penetrated by the roots of plants and can easily be disturbed by earthworms and any other animals that live in the soil.

However, soils may owe their origin to water-action without having received their mineral constituents from river or sea. Wherever there are steep slopes a certain amount of debris is carried downwards by rainwater to be deposited where the gradient is less, near the foot of the slope. Sometimes the amount of disintegrated matter carried down in this way is very considerable, and it may cover an appreciable area. Such deposits are called colluvium, and are said to be colluvial in origin.

Before leaving the subject of water-action it may

be mentioned that almost everywhere the surface debris, the raw mineral material from which the soil is built, has been moved at least a short distance from its parent material by water, it may not be far, but the fact is often indicated in nature by the admixture with the top few inches of the soil of materials such as pebbles and fragments of rock that have evidently been brought there by the agency of surface water, whether by downwash, by brook, or by river.

(*c*) Due to ice-action. When the mineral part of the soil has been transported by ice, the raw ingredients for soil formation are generally in the form of such geological materials as boulder-clay, a term which includes deposits of a wide range of texture from tenacious clays containing ice scratched pebbles and boulders to sandy debris which the ice deposited.

(*d*) Due to wind-action. Raw materials for soil formation are being deposited by the agency of wind wherever sand dunes are being built up, good examples are provided by those of the coasts of Lancashire, Caernarvonshire, and Kent. In past ages, wind-borne debris has repeatedly given rise to rocks. In the case of Loess the deposit has remained in a relatively unconsolidated state and is readily converted into soil: the river valleys of S.E. England are rich in this material, which forms the well-known brick-earth of the Thames Valley and of other valleys in the region.

Soil colour is a natural property useful in field descriptions of soils and of their individual horizons, and is to some extent an indication of chemical or mineralogical composition, though it must be remembered that different conditions of lighting produce

different colour effects; this is readily seen by comparison of the colours of the same soil at noon on a dull day and just before sundown in bright sunlight. Another point to be borne in mind is that very small quantities of some substances profoundly affect the colour of the soil. This is noticeably the case with some of the oxides of iron and with some organic compounds. In a soil formed from a brown or red parent material, where the brown or red colour was due to the presence of compounds of iron, the removal of those colouring matters by rainwater passing downwards through the soil (a process called leaching) will frequently result in turning that part of the soil grey or giving it a greyish tinge; in this instance the grey colour is an index of the process of leaching. Anaerobic (i.e. airless and consequently oxygen-less) conditions in soils, such as are found in water-logged situations, result in the production of substances giving a bluish-grey colour to part of the soil. This correlation of colour with water-logging provides a useful index in studying such soils. One further example is provided by the effect of the presence of chalk in a soil: this substance naturally tends to give a whitish-grey colour to the soils in which it occurs.

(iii) SOIL-COLOUR.

Colour, though it is one of the most obvious of the natural properties of any soil, is very difficult indeed to express in a form that will be of value for the field description and comparison of soils. A number of methods has been devised for recording colours. For example, the use of a colour-chart, consisting of a complete range of colours, makes it possible to obtain a match for any soil or any part of a soil. Again, a series of coloured surfaces can be manipulated to compose a rotating field of colour

to match the colour of the soil. But whether these or other methods are used to measure the colour of soil, none has yet been found that is really adequate and none has received universal acceptance. Apart from any objections to the apparatus used, such as the fading of coloured surfaces and difficulties of standardization, it has also to be remembered that slight changes in moisture content of the soil or in its compaction or in the condition of the surface examined, may change the colour of the soil. The colour and intensity of the light illuminating the soil or the colour-meter also affect the result. Thus in our attempt to record the colour of any soil in the field we are driven back to a very general estimate. It is best to begin by stating the fundamental colour of the soil, black, red, white, brown, yellow, grey and so on. Then we may qualify this statement by using an adverb, describing the soil as *pale* yellow, *greyish* brown, *brownish* grey, etc. This gives us at least a rough working description of the colour by which to convey our ideas to other people. So the accurate description of soil-colour as seen in the field is just another of those apparently simple tasks which is very difficult to carry out when it comes to the point. We have to be content with an approximation to the truth.

(IV.) TOPOGRAPHY.

We generally picture good agricultural soils as occurring in flat or gently undulating country but soils are found under every topographic condition from that of the steeply sloping mountain side to one of seemingly unbroken level expanse of plain or marshland. These are major topographic characteristics and are of great importance in determining the natural and economic capabilities of soils. Altitude is also a factor in determining the nature

of a soil, and aspect has a modifying influence, because it determines the degree of insolation (i.e. the amount of heat received direct from the sun) and consequently the relative warmth of the soil; thus in a mountainous region, soils at a high altitude exist under climatic conditions which resemble those of soils much further from the equator, while our soils on slopes facing south obviously receive much greater heat from the sun than those sloping in the opposite direction. Proximity to the sea introduces a climatic factor which has an influence upon the soil and is of some

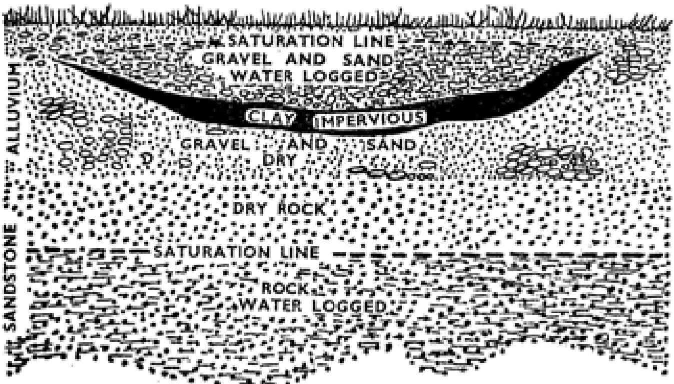


Figure 24. Some Water Conditions

In alluvium (material deposited by river-water) and in the sandstone upon which it lies. In the case here illustrated the top of the sandstone rock is dry but, below the saturation-line, this pervious rock is water-logged. The alluvium consists mainly of gravel and sand, and much of it is dry because the water readily passes through these materials and runs down into the sandstone rock below; but in some places the alluvium consists of deposits of impervious clay and by these, especially if basin-shaped, water is held up and the gravel and sand immediately above the clay are water-logged. In this instance the saturation line above the clay indicates the position of the water-table, which from its separation from the water-table in the sandstone below, is called a *perched water-table*. *Drawn by S.G.B.-B.*

economic importance. The position of a soil at the bottom of a valley, or on the slopes of a hill, is influenced not only by the gradient but also by the fact that the valley floor is much more subject to late spring frosts than the slopes of the hill above.

Minor topographic features, especially differences of micro-relief (i.e. small differences of altitude from a few inches up to a few feet), may be responsible for great differences in the economic value of soils in very flat areas. A good example is to be found in

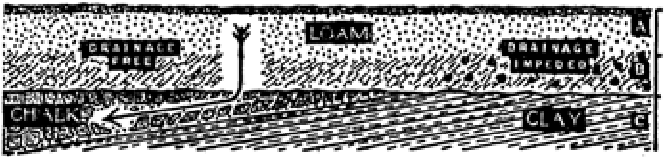


Figure 25. **Differences of Natural Drainage.**
The soil to left overlies Chalk; drainage, indicated by the arrow, is unimpeded. Below the soil on the right is Clay; here the soil becomes water-logged and black concretions develop. A, B, C, horizons of the soil-profile. *Drawn by S.G.B.-B.*

marshlands, where a very small difference in altitude makes all the difference between a very fertile soil most satisfactorily placed with ideal water conditions, and one close at hand, a foot or two nearer sea-level, which suffers from badly impeded drainage. The one may provide herbage* of the highest value for fattening stock and the other be incapable of doing more than supporting, without fattening, a much smaller number of animals.

Through some soils, the rain that falls upon the surface drains rapidly away and soon leaves the soil as dry as before, there are other soils that are constantly water-logged, and between these there are

*See index and glossary.

many intermediate conditions. An important factor in determining the water condition of a soil is its natural drainage, and thoroughly to understand natural drainage we must enter into a number of geological topics, but before turning to these, it may help to make the whole subject clear if we briefly recall what happens to water falling as rain in a district where the soil of a pasture overlies a soft sandstone. Instances of this kind are to be met with in many parts of Great Britain—e.g. in many places in the west and N.W. Midlands of England. The rainwater (meteoric water as it is sometimes technically called) falls upon the herbage, where some of it evaporates; the rest passes down into the turf and so becomes soil-water. Some of this is absorbed by the roots of living plants which, through their leaves, transpire much of it back again into the air. The surplus water seeps down (we use the verb seep technically here) through the open, well-aerated soil among the particles of sand, silt and clay (about 75%, 15%, 10% of the total bulk respectively). All these particles are moistened on their outer surfaces by a thin covering or pellicle of water (pellicular water). As soon as the moistening is complete, and not before, the excess of water seeps down as gravity water to a lower level until, sooner or later, (according to the physical configuration and geological arrangement of the rocks) it approaches the depth at which all the interstices and pores of the material (in this instance, loose sandstone) are completely filled with water. This water is not stagnant, it is slowly running out of the rock at some distant point, it runs slowly because it is passing through very small irregular channels between the sand grains and so friction and capillarity retard its movement. Thus

(v) NATURAL DRAINAGE.

the incoming rainwater having seeped down through the soil takes its place in the slow stream in the water-logged rock and gradually percolates (this is the correct term for movement in granular water-logged material) through the substance of the rock. The uppermost limit of the water-logged rock is called the water-table, and this varies less in height than might be expected because water runs out at about the same rate as it comes down from the soil above. The water below the water-table is called ground-water. After periods of very heavy rain, the water-table rises to a maximum, and in times of drought, it falls to a minimum, so that in winter the water-table is high, while in summer it tends to be low.

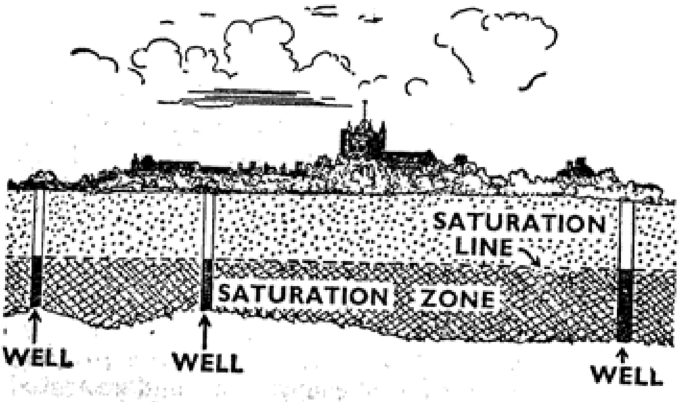


Figure 26. Wells in Pervious Rock.
Here the ground is level. The water in the wells stands at the height of the saturation line. *Drawn by S.G.B.-B.*

Some Geological Factors in Natural Drainage.

There are times when, the weather remaining dry for a long time, there is no water to seep down through the materials, soil and rock alike, that may

lie between the surface of the ground and the water-table. In this absence of water, air alone fills the spaces between the particles of soil and rock in this layer, and the name "zone of aeration" applied at all times to the whole stratum between the surface of the ground and the water-table, becomes especially appropriate.

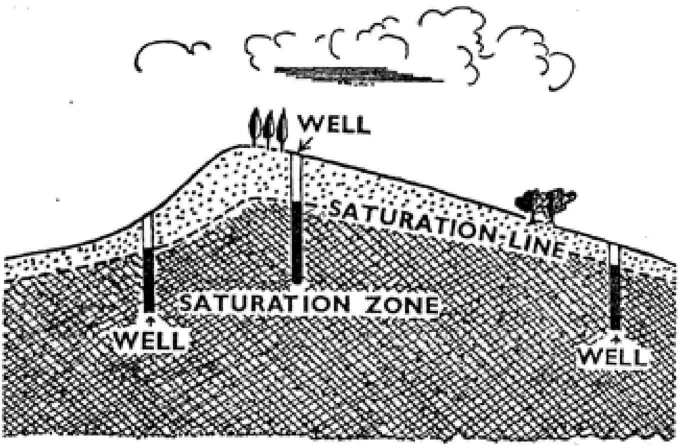


Figure 27. Wells in Hilly Country on Pervious Rock.
The saturation line is roughly parallel to the surface of the ground and the water in the wells stands everywhere at the height of the saturation line. *Drawn by S.G.B.-B.*

At such times, when rock and soil are at their driest, the free water below the water-table tends to be drawn up by capillary attraction into the interstices of the lowest part of the zone of aeration. This layer of water-filled capillaries has been called the capillary fringe.

We turn next to some geological questions which

have a bearing upon natural drainage. Porosity is an important property of rocks in this connection. We have seen already that sandstone is a rock in which there are many spaces or pores which are easily filled up with water. It is, therefore, described as porous. In distinction from some other rocks the pores are comparatively large in sandstones. In clay, the pores are extremely small but dry clays will take up

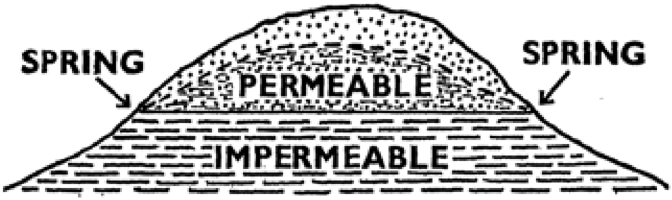


Figure 28. The occurrence of Springs.
The broken line indicates the saturation line; under gravity this reaches the surface on the hillside and water runs out as a spring.
Drawn by S.G.B.-B.

as much as 50% of their own bulk of water. Some rocks are hardly porous at all, among such are granite, quartzite, and some compact limestones.

Natural drainage is much modified by the permeability or impermeability of rocks; these properties are often independent of porosity, for permeability is the property which allows water to pass through a mass of rock. (The term pervious is practically synonymous with permeable. In the word permeable the emphasis is upon the act of passing through, in the case of pervious the emphasis is upon the openings through which the water can pass.) Many compact limestones which are not porous are readily permeable, because water passes directly down through the joints which are characteristic of limestones.

Sandstone, which is porous, is permeable because the water passes through the minute channels between the grains. Clay is porous, but because the pores are so minute they normally remain filled with water which does not run out, and so, since there are no joints in this rock, it is impermeable. Some rocks are non-porous and impermeable, among these may be mentioned dolerite, when it is not fissured.

As we have already seen, the water-table (occurring only in permeable rock) is the name given to the upper-

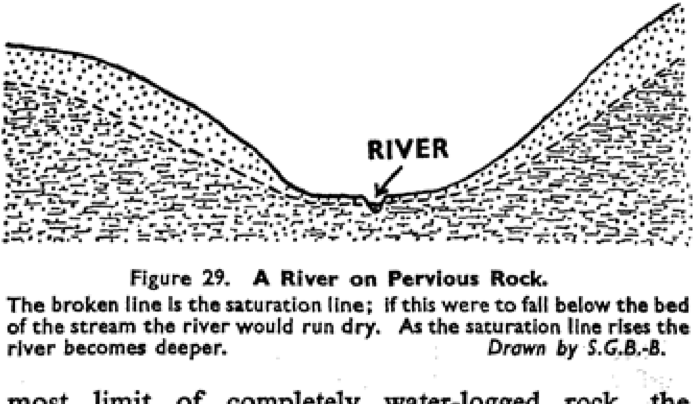


Figure 29. **A River on Pervious Rock.**
The broken line is the saturation line; if this were to fall below the bed of the stream the river would run dry. As the saturation line rises the river becomes deeper. *Drawn by S.G.B.-B.*

most limit of completely water-logged rock, the top, therefore, of the saturation zone. Thus it is obvious that the water-table is a plane and that in section it will appear merely as a line. This side-view of the water-table we call the saturation-line. In flat country the water-table (or in section the saturation line) is parallel to the surface of the ground. This is shewn by the fact that all wells sunk into the saturation zone in such an area are full of water up to the same level, which is the saturation line. In other words the surface of the water in the wells is continuous with the water-table.

In hilly regions the case is a little different. Here the water-table is found to correspond in shape very roughly with the shape of the hill. Near the top of the hill, however, the water-table is farther from the surface, and wells have to be deeper to reach it and tap the ground-water than is the case further downhill. In fact as we go from the top to the bottom of the hill the water-table approaches nearer and nearer to the surface and the wells are shallower and shallower.

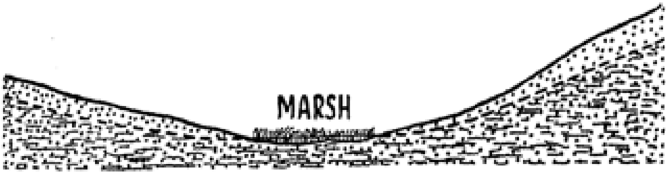


Figure 30. A Marsh on Pervious Rock.
The broken line is the saturation line, below which the rock (here a sandstone) is water-logged. The topography is such that the saturation-line comes out at the surface and a Marsh results.
Drawn by S.G.B.-B.

The water-table is held in this way as a curved surface because percolation is retarded by friction and capillarity, and the water-table is held in this shape for long periods because the ground-water is replenished by the seepage of soil-water. The form taken by the water-gradient (i.e. the slope of the water-table from the highest point to the bottom of the hill) is due to the balance between the quantity of water percolating downwards (the speed of percolation being regulated by friction and capillarity) and the quantity of soil-water seeping down to the saturation zone.

The water in the saturation zone percolates through the channels in the rock and runs out very slowly

under gravity wherever there is freedom for it to do so. Thus there are places where the water-table reaches the surface, and wherever this happens and the water runs out, a spring, or a stream, or a marsh or a body of water such as a pond or lake results. The surface of the water in stream, marsh, and pond, like the surface of the water in the wells already considered, is continuous with the water-table.

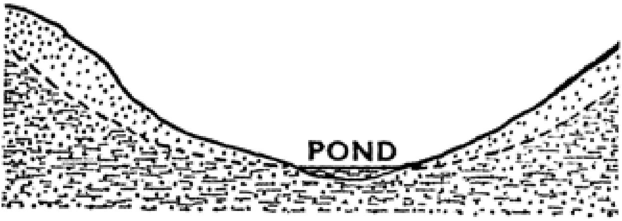


Figure 31. A Pond on Pervious Rock.
The saturation line comes to the surface and a pond occurs.
Drawn by S.G.B.-B.

In the zone of aeration, strata of impermeable material may occur to hold up the water locally above the level of the ordinary water table. In such a case a pocket of water-logged material is thus formed, and this is known as a perched water-table.

The effects of water conditions are important for crops and are generally best for them when the soil itself is capable of holding a good supply of pellicular water for a long time and where the zone of aeration is deep enough to give the roots plenty of room for development.

Natural drainage is generally expressed in soil descriptions by such terms as excessive, satisfactory, deficient, or impeded. Excessive natural drainage produces very dry conditions in periods of drought and plants suffer as a result, those with deep roots

or a low transpiration rate suffer least. Where the drainage is excessive or satisfactory, each soil-horizon is evenly coloured, there is no mottling of the soil and no rusty markings, there is an absence of any bluish-grey moist horizon. If natural drainage is deficient or impeded it means that the water is held in the soil by underground conditions and certain plants suffer, especially those that require a deep rooting system. The signs of impeded drainage include the formation of hydrated oxides of iron and the presence of ferrous substances, the former are brown and yellow, and some of the latter bluish-grey.

Details are not fully understood, but they may be explained tentatively as follows: Horizons of the soil that are regularly or seasonally wet, but not water-logged, tend to be differentiated in the space of a few inches into wetter and drier parts, and places that are less or better penetrated by air. In each case either water or air is important. These extremely local differences in water and air (oxygen) content, emphasized by fluctuations in the prevailing conditions, lead to the establishment of differences in the nature and quantity of different substances present, especially differently coloured compounds of iron. The general result is a mottled effect which thus acts as an index of impeded drainage.

Apparently where there is a suitable fluctuation of the water-table, ferrous iron compounds may be brought into a horizon of the soil in solution, and afterwards left there to be oxidized into insoluble ferric substances when the water recedes and is succeeded by air. These oxidized substances may be hydrated ferric oxides, of which a series has been named, limonite being the best known; they frequently occur as concretions, and these may be isolated and present only in small

numbers or be associated in such profusion as to form a more or less continuous layer. Such a layer, especially when continuous, is called a pan, and its constituent material has many local names, such as "crowstone," "catsbrains," and "shrave."

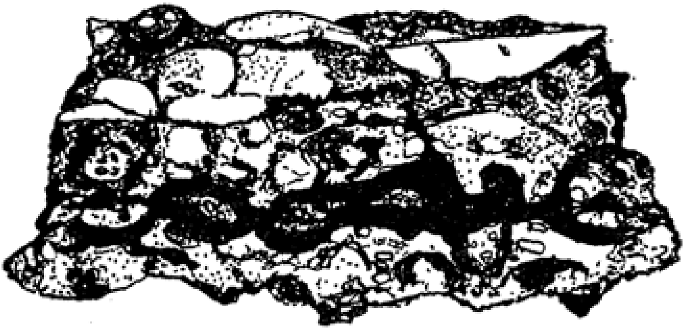


Figure 32. Piece of an "Iron Pan,"

From a ground water podzol in valley gravel, Guildford, Surrey. The cemented soil particles form a mass of *crowstone*. ½ natural size.

Drawn by S.G.B.-B.

(vi.) SOIL PROFILE.

Anyone brought up on the land has the opportunity to learn very early in life that below the familiar surface soil, which is turned by the plough, are materials that are very different in appearance and very different to handle. The farm labourer digging a hole for a gate-post quickly penetrates below the layer that is usually cultivated and brings up with his spade earth that is different in colour, texture and consistency from that of his first spadeful. If he digs deep enough change may succeed change, and finally he may reach unweathered rock. This succession of differences, especially clearly exposed on the wall of a sandpit

or quarry or of some excavation such as a newly-made railway or road-cutting is called a *soil-profile.*

We can hardly exaggerate the importance of the soil-profile as an intrinsic record of soil properties and capabilities. If the soil-profile is studied we shall be able, with ease, to determine colour, chemical reaction, texture and structure, and to find evidences of the mode of formation and geological history of the soil and of its natural drainage.

In moist temperate climates such as that of the British Isles typical soils exhibit a soil-profile with three main divisions, each of which can frequently be sub-divided. Perhaps the ideal way to see this is to look at such a soil-profile on the wall of a pit specially dug for the purpose. We ought then readily to distinguish an uppermost relatively light-textured and relatively uncompacted layer (or horizon, as it is more correctly called). This uppermost horizon will be largely turned by the spade or plough in the ordinary cultivation of garden and field, and, from the fact that it contains a good deal of plant debris produced by the decay of roots, stems and leaves, it may have a darker hue than any other part of the soil-profile. This horizon is frequently dark brown with a greyish tinge. The greyish tinge is significant and needs a little explanation.

The colours red, brown and yellow, so frequently seen in rocks, and sometimes transmitted to soils, are practically always due to the presence of chemical substances containing iron. Some of the colour, especially that due to hydrated oxides of iron might be expected to be transmitted, sometimes somewhat modified, in any material such as soil derived by weathering from rocks so coloured. Now the greyish tinge seen in the surface horizon is due not so much to the presence of anything as to the absence of things

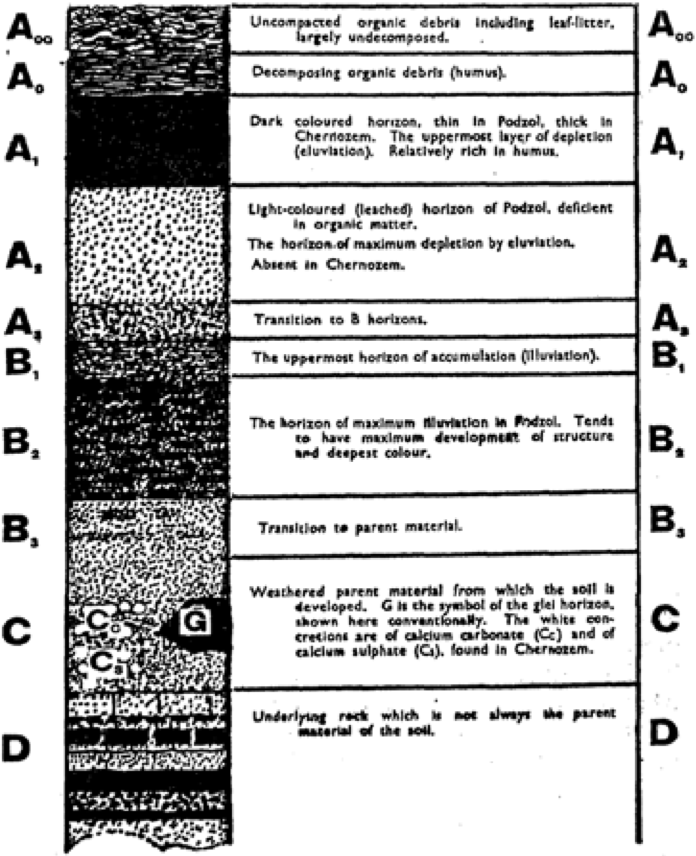


Figure 33. The Soil-Profile.

Diagram to explain symbols used in descriptions and the sequence of layers (technically called *horizons*). *Drawn by S.G.B.-B.*

that give other colours; in this topmost part of the soil the colouring substances have been removed.

As a matter of fact they have been washed out and carried down deeper into the ground by water that has had its solvent properties reinforced by absorption of carbon dioxide produced in the turf by the decay of plant materials. Close examination generally reveals bleached sand grains in the soil and any small stones present may be bleached as well.

The horizon we have just considered is usually about eight or nine inches deep. Below it, there is generally another horizon with a greyish tinge, but the soil is lighter in colour and the greyness of the material is generally more striking to the eye. Again, if we look closely we see that individual sand grains in it are bleached.

These two top horizons of the soil form its uppermost division. They frequently have a brown colour, but it is the greyish tinge that is especially important because it indicates that water passing down through the soil has removed substances which might have given it a brighter colour. This solution and downward washing of materials by water (leaching) is very important as one of the soil-forming processes. By it the uppermost division of the soil, comprising what are called the A horizons of the soil, is depleted of iron compounds which find their way into lower horizons of the soil. From its effect upon colour, this loss of substances containing iron removed especially in the form of sesquioxide of iron (Fe_2O_3) is the most striking result of the downward passage of water, but it is by no means the only movement of soil constituents that is brought about by it. There is also the removal of compounds of aluminium carried down especially as aluminium sesquioxide (Al_2O_3), which is effected at the same time. There is also a gradual removal of clay and silt, and a constant downward movement of the products of plant

decay (humus). From the fact that sesquioxides of iron and aluminium, as well as clay and humus, are removed, this division of the soil is obviously a zone of depletion or eluviation (equivalent to Latin *ex*, out; *lavare*, to wash).

Below the A horizons of the soil-profile we shall find soil that has no greyish tinge. Here we may expect yellow, brown or red coloration, something brighter as a rule than we found in the uppermost parts of the soil-profile. These characteristics are due to the iron compounds that have been derived from the soil above, sometimes darkened by the humus similarly brought in. The addition of clay and silt from the zone of depletion makes this part of the soil-profile heavier than the horizons above and also makes it more compact. Sometimes the iron compounds that are brought down from above form a cement and bind the particles of soil together; this is especially effective when the original material of the horizon was sand or gravel, but of course it also depends upon the amount of iron compounds originally present in the topmost part of the profile.

The division of the soil-profile which we have just described is evidently a division in which there is accumulation, its horizons, which are frequently three, are called the B horizons or horizons of illuviation (equivalent to Latin *in*, into; *lavare*, to wash).

Below the horizons of accumulation we come upon the rock. Here we find a certain amount of weathering has already taken place in the upper part, and it will eventually be incorporated in the lowest part of the B horizons of the soil. The weathering rock is designated the C division of the soil-profile, and it is sometimes sub-divided according to the degree of weathering that different parts of it have undergone. Completely unweathered rock is not

part of the soil-profile, but it is sometimes shewn in diagrams and other illustrations of the soil, and it is then appropriate to distinguish it by the letter D.

Generally speaking soils of limestone areas are alkaline in reaction, those of well drained sandstones we expect to find acid, and in an uncultivated state each will have its characteristic flora. Here is a link between pedology and plant-ecology.

(vii.) CHEMICAL REACTION.

From the point of view of classification it is almost sufficient to know whether a soil is acid, neutral or alkaline, but it is often of interest to know a little more than this, to obtain some degree of accuracy about the "acidness"—the strength of the acidity—or about the alkalinity. It is usual to express acidity or alkalinity in what is called the pH value. There is no need to enter here into the method of arriving at this quantitative representation which will be found discussed in detail in modern text books of chemistry, and it may be sufficient to point out that the pH value of a neutral soil is 7; acidity is represented by lower numbers, alkalinity by higher ones. The United States Department of Agriculture, in its *Yearbook of Agriculture*, 1938, entitled "Soils and Men," gives the following figures for the pH value of soils—

Extremely acid . .	below 4·5
Very strongly acid . .	4·5—5·0
Strongly acid . .	5·1—5·5
Medium acid . .	5·6—6·0
Slightly acid . .	6·1—6·5
Neutral . . .	6·6—7·3
Mildly alkaline . .	7·4—8·0
Strongly alkaline . .	8·1—9·0
Very strongly alkaline .	9·1 and higher

I am indebted to Dr. N. H. Pizer for the figures which he suggests for the guidance of farmers in S.E. England. They will be found in Appendix V, page 284.

J. S. Joffe, in his book *Pedology*, gives an instance of a podzol in New Jersey of which the surface soil gave a pH value of 4·2 in a water extract, and more acid soils than that have been recorded in America.

In S.E. England, Dr. Pizer and Mr. I. Clewley give me instances of very acid soils. One at Brenchley, a silty clay loam, has a pH of 4·4, while a fine sandy loam at Borough Green has a pH of 3·8.

In Solonetz soils, to which attention will be drawn when we come to page 231, sodium hydroxide may be present in sufficient quantities to make the soil very strongly alkaline, and incapable of supporting any plants at all.

There are various ways of determining the pH of soils, including some of great refinement, but there is one that is to some extent useful in the field; it is a colorometric method. A little of the soil to be tested is added to a liquid indicator, a little of which is afterwards taken up into a capillary tube to be compared with a series of similar tubes filled with prepared indicator, the pH value of each of which is known. The tube is matched and an approximate reading for the pH value of the soil is thus very quickly obtained. For technical reasons this method is not always to be relied upon and a laboratory determination by a more refined procedure should always supplement the field determination in any case where accuracy is really desired.

Gove Hambidge writes in "Climate and Man," (United States *Yearbook of Agriculture*, 1941), page 4: "The distinction between climate and weather

is more or less artificial, since the climate of a place is merely a build-up of all the weather from day to day, and the weather is merely a day-by-day break-down of the climate. It seems to be a useful distinction, however. . . ."

(viii.) CLIMATE.

A. Austin Miller, in his *Climatology*, page 6, remarks: "The climate of a place is defined by a number of *elements*, or component parts, such as the temperature and humidity of the air, the rainfall, the wind velocity, the duration of sunshine, and a host of others of less importance and less significance to man. These elements are the results of the interaction of a number of *factors*, or determining causes, such as latitude, wind direction, distance from the sea, relief, soil type, vegetation, etc."

In the great spaces of the Soviet Union climate forced itself upon the notice of nineteenth century soil investigators. It stood self-proclaimed as a vital and outstanding factor in determining the characteristic features of the great soil groups, the assemblage of zonal soils and although human ingenuity suggested other explanations for their distribution in Russia, climate was eventually accepted as being of first importance. The study of this aspect of climatic influence belongs to the consideration of the great soil-groups of the world to which attention is directed on pp. 211 to 242. When the influence of climate upon soil is mentioned it is generally this broad regional influence that is called to mind.

But there are other ways in which climate is related to the soil. Take England and Wales: as a whole the climate is so much affected by proximity to the Atlantic and the warming effects of the Gulf Stream that we may speak of it in a general way as being maritime; this means, at least, smaller difference

between winter and summer temperatures than occur under continental conditions, and consequently we should not expect the soils of England and Wales to be like those of continental areas within the same limits of latitude. This is a comparatively local consideration of the influence of climate in producing special soil conditions, but we can trace climatic influences with a differential effect on smaller areas than that of the whole of England and Wales.

If we neither go into too great details nor expect very sharply defined boundaries between one type of climate and another, we may, from a climatic point of view, first divide England and Wales into two parts—a western and an eastern. The western part includes the mountains and hills of the Lake District, of Wales and of Devon and Cornwall, with part of the south coast. These western areas are especially subjected to maritime influences which cause warmer winters and cooler summers than characterize continental localities in the same latitude. These areas in our own country, owing to a prevailing S.W. wind and to the hilly topography are also subject to higher rainfall than the rest of England and Wales. Turning to the eastern side of the country we find that the rainfall is lower than that of the west, the winters are colder and, except in the north, the summers are hotter.

But we can go a step further—nor shall we have finished then—and sub-divide the two main areas. We can cut up the western part into north, central, and south, to include the three districts already mentioned—the Lake District, Wales and Devon, with Cornwall respectively. In the east we may distinguish the driest region between the Thames and the Humber, and divide it again into the Midland area with a cold winter and a hot summer, and the

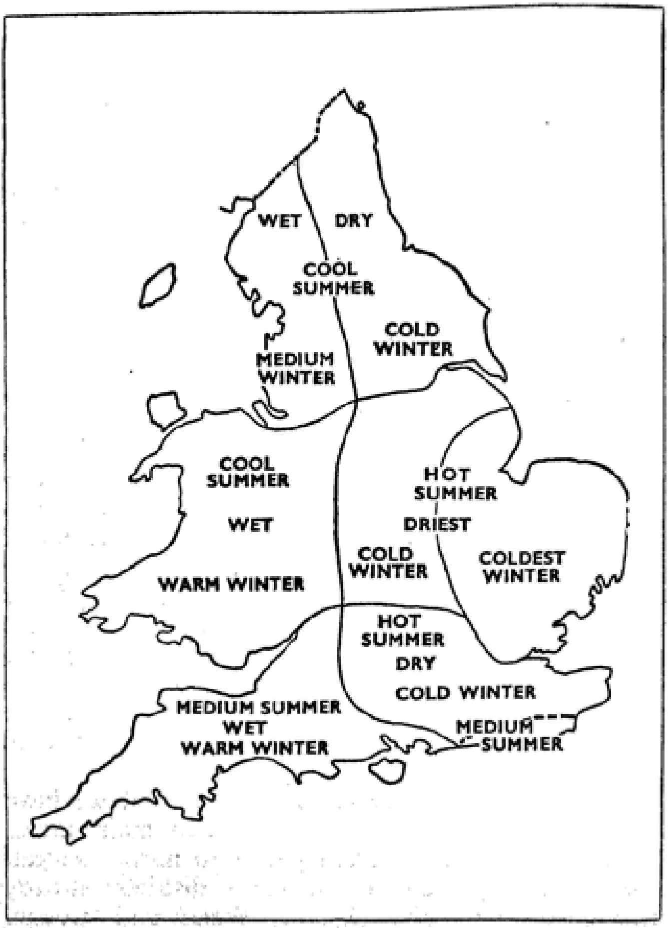


Figure 34.
The general distribution of differences of climate in England and Wales.
Compiled and drawn by S.G.B.-B.

East Anglian region with the coldest winter and a hot summer. The area north of the Humber has a dry climate with cold winter and cool summer. The south-east, south of the Thames, has a dry climate with cold winter and hot summer. In all cases the coastal strip has climates which are modified by proximity to the sea. We can, moreover, correlate all the sub-divisions we have enumerated, with differences in agriculture. In East Anglia the winters are very cold, the summers hot, and the rainfall is very low. This is correlated with arable farming, especially the growth of wheat and other cereals; the climate is unfavourable for grassland. Compare this with the Cheshire plain, which is part of the west central sub-division I have made; here rainfall is high, winters are warm, summers cool. It is ideal for the growth of grass, so here we have excellent pastures and dairy farming.

But let us leave these fairly large areas and turn to something smaller and still more local. There is, for example, that influence of climate which determines that some soils in a relatively small area differ from all those of the surrounding neighbourhood in being what are generally called "early" soils. In Kent there are places like the little regions round the Hundred of Hoo and Sandwich respectively which are noted for the early crops they produce, perhaps a fortnight or so before they are ready in other parts of the districts in which they occur. Various factors are locally responsible for these considerable climatic differences.

Still more local are differences in climate which may yet greatly influence the value of the soils on a single farm or even in an individual field. The presence of a wind-break of trees—tress planted for protection from cold or violent winds—will, of course, make

a difference which is really a climatic one. The occurrence of woodland to the east of a field will often mean that in the spring the ground frost will persist in the shadow of the trees on that side of the field until an hour by which the morning sun has

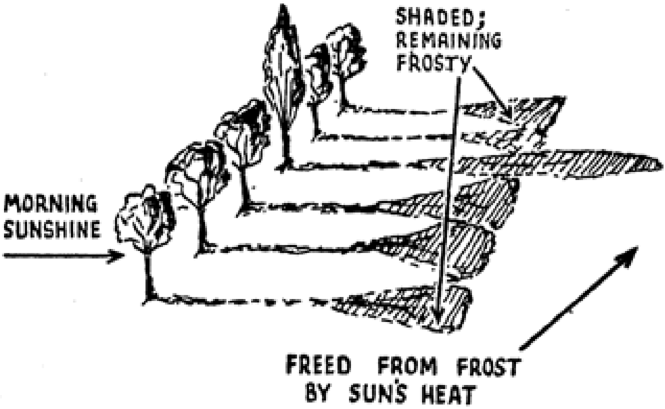


Figure 35. **Local small differences of Climate.**
Diagram to illustrate the effect of trees in shading soil from the sun's heat. *Drawn by S.G.B.-B.*

already had ample time to warm up the surface of the soil on the open ground free from the shade of the woodland. In a case like that the soil on the cold side of the field may still retain far too much moisture to be ploughed with advantage at a time when the rest of the field is quite ready for cultivation.

On a farm with undulating land there may occur on the opposite sides of a hill or of a valley two slopes, one so inclined as to receive all the benefit of the sun's warmth, the other so turned as to receive a minimum of the solar heat. These different insola-

tions (exposures to the rays of the sun) are climatic *elements*, although the *factors* producing them are topographical. Again on farms with land that is

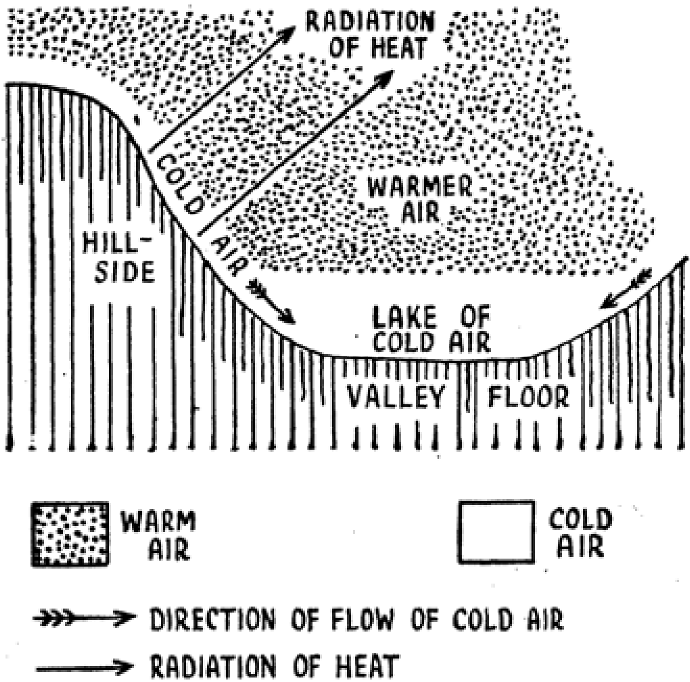


Figure 36. **Local Climate in a Valley.**
The warmer air rises and cold air flows down the slopes to form a lake of cold air on the floor of the valley. *Drawn by S.G.B.-B.*

even moderately hilly, there may be very localized differences of temperature on calm clear nights. By radiation of heat after sundown the soil and the air immediately over it are cooled more rapidly than

the air a few feet or a few yards from the ground In this way the air nearest to the soil becomes denser and heavier than that above it and consequently, if the ground in question is part of a slope, the cold air will flow slowly downhill and form a pond or lake of chilly air at the bottom of the valley or indeed in any depression in the ground. This explains why, in low-lying places, spring frosts often cause damage to horticultural plants, particularly to fruits, and especially to strawberries which not only flower early but also grow close to the ground. According to C. E. Cornford, a common speed for the downward flow of cold air under such circumstances is one mile per hour, and a common temperature-difference between a valley bottom and a hill top 300 feet higher is 8°F., but he says that both these figures would be greatly increased in a very sharp frost. It often happens that while a crop in the depression suffers from frost damage one grown higher up the slope escapes.

Dr. N. H. Pizer points out to me that the same cause indirectly affects the fertility of the soil of pastures by encouraging cattle to lie at night on the higher ground in a field because it is warm in the colder hours. As a result, since most of the droppings and urine are made at night those parts of the pasture are especially enriched. When such a pasture is ploughed the crops grown on the higher land are often much better owing to the accumulation of potash, phosphate, organic matter and other plant foods.

The instances that have been mentioned here have obvious results, but even smaller climatic differences no doubt have small effects upon plant growth. Little differences in climatic elements within the soil itself or under differences of vegetation hardly noticeable to the casual observer and so on may produce better

or worse conditions which in some cases may be more important than spectacular.

So in many ways, great and small, climate helps to determine both the nature and the capabilities of the soil.

CHAPTER VII

PUTTING THEORY INTO PRACTICE

In this short chapter information obtained in the last chapter is put to the practical test. The examples selected shew how universal this scheme of soil-definition and recognition is; they come from England, Canada, U.S.A., and Australia.

THE EIGHT POINTS IN USE.

WE have now discussed in some detail each of the eight soil properties used in local soil classification (as distinct from the classification of soils on a continental scale). Two soils that are alike in all these eight points are classified in the same *soil-series.*

ACTUAL EXAMPLES.

There is nothing like trying tools out for emphasizing the way to use them, so let us take a few actual examples of the way in which these eight properties may be used for the establishment of soil-series in different places. In each case the data given in the literature are used and descriptions are modified where necessary to give uniformity to the examples as a whole.

BASCHURCH SERIES

(W. MORLEY DAVIES AND G. OWEN)

Geology: Pleistocene. Mixture of Welsh and Northern (Triassic) light glacial drift. Pebbles mainly composed of Palæozoic shale material with granites, quartzites, etc., of Northern origin.

Deposition: Ice.
Colour: Dark greyish brown.
Topography: Gently undulating.
Natural Drainage: Free.
Soil-profile:

0—8″ Dark greyish-brown sandy and gritty light loam. Crumb structure. Many pebbles of Welsh and Northern origin.

8—36″ Paler brown sandy and gritty light loam, rather more friable than top layer. Pebbly. Earthworm burrows occur in this horizon. Followed by similar material.

Chemical reaction: pH 7·63.
Climate: That of North Shropshire.

CYPRESS SERIES

(A. H. Joel, F. H. Edmunds, J. Mitchell, and H. W. E. Larson)

Geology: Mainly glacial till.
Deposition: Ice.
Colour: Very dark brown.
Topography: Generally undulating.
Natural Drainage: Generally efficient.
Soil-profile:

A_1 2 or 3″ Very dark brown to almost black fine granular horizon.

A_2 12 or 15″ Brown to light brown, somewhat heavier and more compact, columnar horizon.

B_1 (Zone of calcium carbonate concentration) about 8″ light grey horizon.

B_2 Similar, non-columnar horizon.

C Dark grey with scattered small ferric iron mottlings grading imperceptibly into the parent material.

Chemical reaction: pH about 7·0.
Climate: That of S.W. Saskatchewan, Canada.

SASSAFRAS SERIES

(L. L. Lee)

Geology: Pleistocene, Tertiary and Cretaceous gravels, sands and clays.
Deposition: Sedentary.

Colour: Grey.
Topography: Level to rolling.
Natural Drainage: Good to excessive.
Soil-profile:

- A_0 0—1″ Very dark grey to very dark brown leaf mould containing a little sand.
- A_1 1—3″ Grey sand grading into yellowish grey sand, loose.
- A_2 3—8″ Greyish-yellow sand, loose.
- A_3 8—16″ Yellow to light coloured orange-yellow sand, loose.
- B 16—20″ Yellowish brown sand, slightly loamy, loose.
- C 20—36″ Yellowish brown sand containing lenses of gravel, loose.

Chemical reaction: Acid.
Climate: That of south-eastern New Jersey, U.S.A.

BROADMOOR SERIES

(F. F. KAY)

Geology: Alluvium.
Deposition: River water.
Colour: Very dark brownish-grey, mottled rust.
Topography: Flat and depressed.
Natural Drainage: Very poor, permanently wet, water-table rarely below 18 inches; regular seasonal flooding.
Soil-profile: 3″ very dark brownish-grey peaty silty clay, becoming rust mottled towards the base, alkaline, very calcareous, slimy consistency, and containing numerous calcareous shells.

2½″ grey calcareous silty clay, alkaline, very mottled (rust), containing calcareous shells.

5″ grey calcareous clay, mottled rust and orange, alkaline, containing calcareous shells.

7½″ pale grey calcareous clay, mottled orange, alkaline, heavier in texture.

Below 18″, darker grey clay (purplish-grey, mottled greenish-grey), becoming darker with depth, alkaline, non-calcareous. This horizon is probably permanently water-logged.

Chemical reaction: pH 7·92.
Climate: That of Sonning-on-Thames, Berks.

WOODBRIDGE SERIES

(C. G. STEPHENS)

Geology: Diabase.
Deposition: Residual.
Colour: Brown.
Topography: Elevated, sloping.
Natural Drainage: Good.
Soil-profile:

A	8″	Brown sandy loam.
B	26″	Brown loam.
C		Brown.

Chemical reaction: pH 6·5.
Climate: That of Franklin area, Huonville, Woodbridge, and Tamar Valley, Tasmania.

The soils of this series are apple-growing soils.

CLATTERBRIDGE SERIES

(A. J. LOW)

Geology: Pleistocene, Boulder Clay.
Deposition: Ice, sedentary and some colluvial.
Colour: Greyish-brown.
Topography: Gently sloping.
Natural Drainage: Impeded.
Soil-profile:

0—5″	Greyish-brown fine sandy loam with iron-stained roots.
5—13″	Greyish-white bleached layer becoming more bleached.
13—18″	Very heavily iron-stained rusty brown sand.
18—23″	Light yellowish-brown sand.
23—26″	Reddish sand with bleached patches and iron stains.
26—54″	Reddish-brown sandy clay—many black particles

Chemical reaction: pH 6·00.
Climate: That of the Wirral Peninsula, N.-W. Cheshire.

These characterizations of the Baschurch Series (Great Britain), the Cypress Series (Canada), Sassafras Series (U.S.A.), Broadmoor Series (Great Britain),

Woodbridge Series (Australia), and Clatterbridge Series (Great Britain) are based upon the data given in publications by authors whose names are indicated above each description. All soils which agree in the whole of the eight points belong to the same soil-series. Thus the Sassafras sand, the Sassafras sandy loam and the Sassafras loam are all essentially alike in Geology, Deposition, Colour, Topography, Natural Drainage, Soil-profile, Chemical reaction, and Climate. These three soils, the Sassafras sand, the Sassafras sandy loam and the Sassafras loam are, however, distinct soils—distinct *soil-types* in pedological terminology—and the only important point in which they differ from one another is in soil-texture. Thus, in characterizing the individual soils within the series, there is one, and only one, very important property to be considered, that of *soil-texture*.

A WORLD-WIDE SCHEME.

CHAPTER VIII

SOIL-TEXTURE

Perhaps no natural property of the soil has been more widely recognized and used in descriptions by farmers, gardeners and scientists than soil-texture. Clays and loams and sandy soils are constantly mentioned in agricultural books, papers and conversations. The farmer generally knows how heavy or how light his own soils are from his experience in cultivating them. In this chapter it is shewn how it is possible to determine this quite quickly upon a first acquaintance with any soil. This part of the book is a very practical part.

EASE OR DIFFICULTY OF CULTIVATION.

Soil texture is a matter of great practical importance. All farmers know from personal experience that soils differ greatly from one another in ease or difficulty of cultivation. A soil that calls for great effort on the part of horses ploughing is generally described as a heavy soil, one that they can plough very easily indeed is a light soil. Between these two extremes of ease and difficulty is the loam. Loam is neither heavy nor light. Now the property of the soil which largely determines ease or difficulty in working is *soil-texture*, a definite and measurable attribute. This property depends upon the sizes of the mineral particles present in the soil and also upon the proportions in which the particles of different sizes occur in it. This may seem rather complicated,

but like many other things concerned with the soil, it is not so difficult to understand if we examine the soil itself.

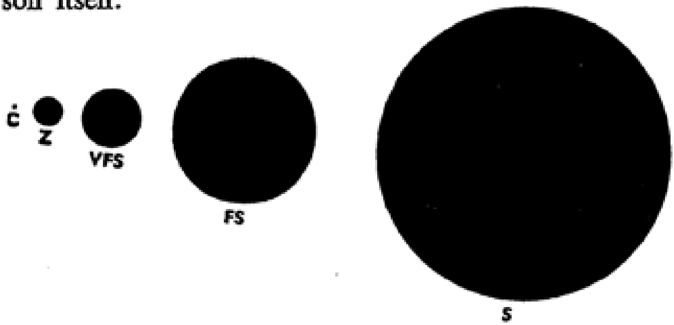


Figure 37. Soil-texture: the relative size of Particles
On the left is represented a clay particle (C) just under $\frac{1}{500}$ of a millimetre in diameter, magnified eighty times. The other representations are of silt (Z), very fine sand (VFS), fine sand (FS) and medium sand (S); all the particles magnified eighty times. *Drawn by S.G.B.-B.*

Pick up a handful of moist but not wet soil, mould the whole handful with your fingers. Is it gritty? If so, you are conscious of the presence of sand grains. If it is not gritty, is it sticky? If so, that stickiness is due to clay. But perhaps it is neither sticky nor gritty, but has, instead, a feeling best described as silky—like the handling of a silk handkerchief. In such a case silt preponderates. There is only one other possibility, and that is that your soil is neither gritty nor silky nor sticky: if it is none of these it means that the grittiness and silkiness and stickiness neutralize one another, and that the soil is therefore a loam. But as we shall return later to consider loams, we shall now revert to the three other things already mentioned. They are sand, silt and clay.

HANDLING SOIL.

These three things are three *grades* of mineral materials and they differ from one another in the size of the individual particles of which they are composed.

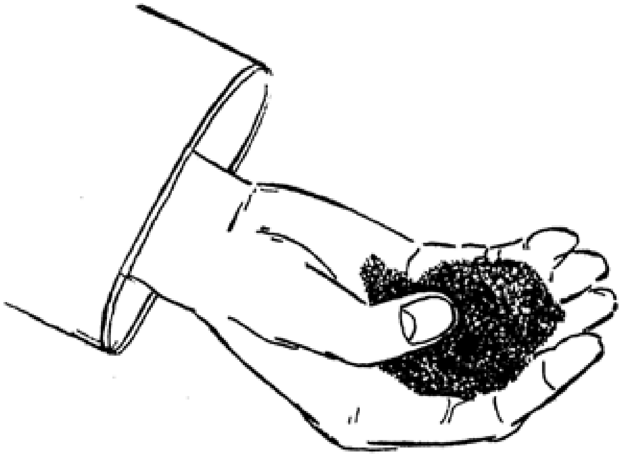


Figure 38. **Soil-texture.**
Testing a handful of soil for grittiness, silkiness and stickiness.
Drawn by H.K.B.-B.

THREE GRADES.

Of these three grades, two, viz.: silt and clay, the silky and the sticky grades, need no sub-division; but with the other grade, sand, it is convenient to recognize four sizes of individual grain. Perhaps when you speak of sand, you visualize some familiar sea-shore sand, and it is quite likely that the particles are about this size :.:. This is *medium sand;* any sand really coarser than this is *coarse sand*, the particles of which are between one millimetre and half-a-millimetre in diameter. Sand with smaller grains

than those of medium sand is *fine sand* with grains $\frac{1}{4}$ to $\frac{1}{10}$ of a millimetre in diameter, and *very fine sand*, of which the grains are $\frac{1}{10}$ to $\frac{1}{20}$ of a millimetre in diameter; these last grains are just visible, individually, to the naked eye.

TWO STANDARDS. Unfortunately, there are two standards of particle-size in use, one is employed by the great army of soil-scientists at work in the United States of America, and elsewhere, and is as follows:—

Fine gravel	2—1 mm.
Coarse sand	1—0·5 mm.
Medium sand	0·5—0·25 mm.
Fine sand	0·25—0·1 mm.
Very fine sand	0·1—0·05 mm.
Silt	0·05—0·005 mm.
Clay	0·005—0 mm.

We may call this the old American scale because even here a slight modification has recently been introduced as follows:—

Silt	0·05—0·002 mm.
Clay	0·002—0 mm.

This may be designated the new American System.

In Great Britain many soil-chemists use the following scale:—

Stones and gravel	over 2 mm.
Coarse sand	2·0—0·2 mm.
Fine sand	0·2—0·02 mm.
Silt	0·02—0·002 mm.
Clay	0·002—0 mm.

In this present book, except where otherwise stated, the old American scale is used, mainly because it can best be correlated with the soil-texture as determined in the field.

Mechanical Analysis.

The process of separating the mineral particles in a soil into their three grades: sand, silt, and clay, and the separation of gravel from sand and the different sizes of sand grains from one another, is called *mechanical analysis.* Such an analysis enables us to express in figures the actual proportions of each size of particle present. The methods by which a mechanical analysis can be made are generally described in books dealing with agricultural chemistry and it is not necessary to our present purpose to deal with them.

The Soil (Textural) Classes.

The occurrence of different proportions of sand, silt and clay in different soils and of different sizes of sand particles results in the recognition of a number of different textural classes.

In the official classification of texture by the United States Department of Agriculture twenty textural groups have been established. These are:—

1. Coarse sand.
2. Sand
3. Fine sand.
4. Very fine sand.
5. Loamy coarse sand.
6. Loamy sand.
7. Loamy fine sand.
8. Loamy very fine sand.
9. Coarse sandy loam.
10. Sandy loam.
11. Fine sandy loam.
12. Very fine sandy loam.
13. Loam.
14. Silt loam.
15. Sandy clay loam.
16. Clay loam.

17. Silty clay loam.
18. Sandy clay.
19. Clay.
20. Silty clay.

THE NEW JERSEY SYSTEM.

My friend, Professor Linwood L. Lee, D.Sc., of Rutgers University, New Brunswick, New Jersey, U.S.A., likes the official United States classification for a large area such as the whole of the United States of America, but for the special conditions of the State of New Jersey, and of south-eastern England, with both of which he is familiar, he has found it an advantage to introduce to his English colleagues the New Jersey system which is found to work here extremely well. In the New Jersey system the following textural groups are recognized:—

1—13. Coarse sand to Loam, exactly as in the official United States system.
14. Silty loam.
15. Silt loam.
16. Silty clay loam.
17. Clay loam.
18. Clay.

Each of these twenty classes of the United States system and each of the eighteen classes of the New Jersey System can be recognized in two ways:—

(1) By the method of making a mechanical analysis of the soil which reveals and sets out in figures the proportions of the particles of different sizes that are present in the sample.

(2) By handling the soil and so being able to note certain properties which make it possible to place the sample in its appropriate class. We shall shortly consider this method.

PROPORTIONS OF SAND, SILT AND CLAY.

Dr. Linwood L. Lee has set out limits of the proportions of sand, silt and clay present in the various soil classes.

These classes are grouped into three major groups according to their clay content:

(1) Soils containing less than 20 per cent. clay.

(*a*) Soils containing less than 15% silt and clay are Sands, as follows:—

1. Coarse sand (35% or more fine gravel and coarse sand and less than 50% fine and very fine sands).
2. Sand (35% or more fine gravel, coarse and medium sands, and less than 50% fine and very fine sands).
3. Fine sand (50% or more fine and very fine sands).
4. Very fine sand (50% or more very fine sand).

(*b*) Soils containing 15% to 20% silt and clay are Loamy Sands as follows:—

5. Loamy coarse sand (35% or more fine gravel and coarse sand, and less than 35% fine and very fine sands).
6. Loamy sand (35% or more fine gravel, coarse and medium sands, and less than 35% fine and very fine sands).
7. Loamy fine sand (35% or more fine and very fine sands).
8. Loamy very fine sand (35% or more very fine sand).

(*c*) Soils containing 20% to 50% silt and clay are Sandy Loams, as follows:—

9. Coarse sandy loam (45% or more fine gravel and coarse sand).
10. Sandy loam (25% or more fine gravel, coarse and medium sands and less than 35% very fine sand).
11. Fine sandy loam (50% or more fine sand and less than 25% fine gravel, coarse and medium sands).
12. Very fine sandy loam (35% or more very fine sand).

(*d*) Soils containing 50% or more silt and clay are Loam and Silt Loam.

13. Loam (from 30% to 50% silt and from 30% to 50% sand).
14. Silt loam (50% or more silt, and less than 50% sand).

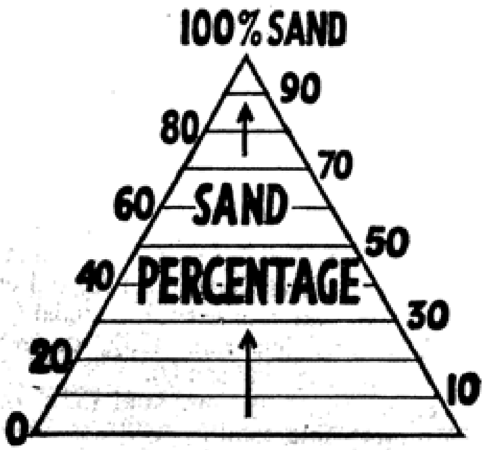


Figure 39. Percentage of Sand in Soil expressed in triangular form, absence of sand represented by the base pure sand by the apex. *S.G.B.-B.*

(2) Soils containing 20% to 30% clay are Clay Loams.

15. Sandy clay loam (less than 30% silt, and from 50% to 80% sand).
16. Clay loam (from 20% to 50% silt and from 20% to 50% sand).
17. Silty clay loam (from 50% to 80% silt and less than 30% sand).

(3) Soils containing 30% or more clay are Clays.

18. Sandy clay (from 30% to 50% clay, less than 20% silt and from 50% to 70% sand).
19. Clay (less than 50% silt, and less than 50% sand).
20. Silty clay (from 30% to 50% clay, from 50% to 70% silt and less than 20% sand).

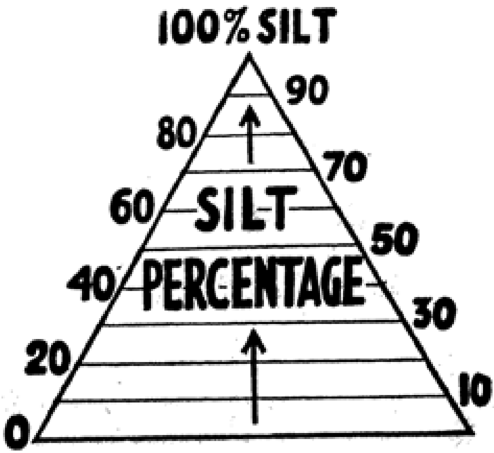


Figure 40. Percentage of Silt in Soil expressed in a triangle, for convenience of comparison with sand and clay in the combined diagram of figure 42, page 150. S.G.B.-B.

SPECIAL SOILS.

In the American system the following highly-organic soils are recognized. They are not included in the twenty official classes, but are regarded as special categories—

(i) Peat is 65% or more organic matter, sometimes mixed with considerable sand, silt and clay.

(ii) Peaty loam is from 20% to 25% organic matter mixed with much sand and silt, with but little clay.

(iii) Muck is from 25% to 65% well-decomposed organic matter mixed with much clay or silt and some sand.

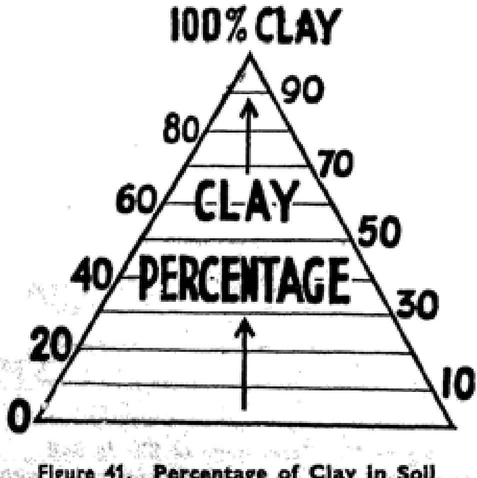


Figure 41. Percentage of Clay in Soil expressed by triangular diagram. S.G.B.-B.

TABLE (after LEE)

OF THE PRINCIPAL TEXTURAL GROUPS, ACCORDING TO THEIR LIMITS OF MECHANICAL COMPOSITION BY AMERICAN STANDARDS (OLD SYSTEM).

Texture (*Soil Class*)	Percentage limits of mechanical composition. Sand	Silt	Clay
Sands	80—100	0—20	0—20
Sandy Loams	50—80	0—50	0—20
Silt Loams	0—50	50—100	0—20
Loams	30—50	30—50	0—20
Silty Clay Loams	0—30	50—80	20—30
Sandy Clay Loams	50—80	0—30	20—30
Clay Loams	20—50	20—50	20—30
Silty Clays	0—20	50—70	30—50
Sandy Clays	50—70	0—20	30—50
Clays	0—50	0—50	30—100

GRAPHICAL REPRESENTATION OF TEXTURE.

Since three grades of mineral particles meet in soils, it is possible to indicate the proportions graphically by means of a diagram which takes the form of an equilateral triangle. This equilateral triangle is composed of three superimposed triangles which we may set out separately and consider individually.

Here each equilateral triangle represents a single grade. The base of each triangle represents 0% of one of the three grades, the apex 100%.

When these three triangles are superimposed to form the equilateral triangle already mentioned, each side of the triangle represents the base of one of the former separate equilateral triangles. This method of indicating texture is shewn in the accompanying figure. (Figure 42).

Milton Whitney, one of the pioneers in soil-survey work in the United States, invented the modern

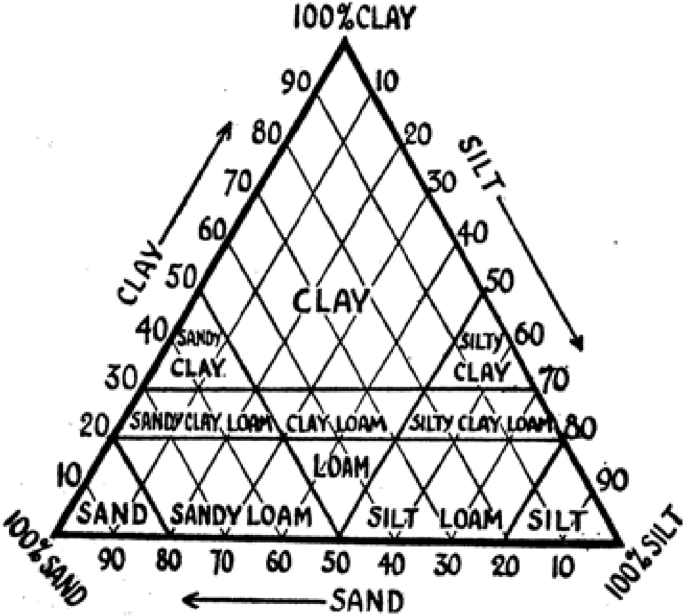


Figure 42. Triangular Soil-Texture Diagram.
Here the three triangular diagrams are superimposed. The clay triangle appears in the same position as before (in figure 41); the silt triangle is turned with its base to the left and apex to the right; the sand triangle is turned with its base to the right and its apex to the left. Reading the percentages of each from their bases we are able to determine the limits of the various textural classes.

Courtesy U.S. Department of Agriculture.

method of handling soil with a view to determining its texture, but it is both interesting and amusing to find that Columella, the Roman agricultural author in the first century of the Christian era, wrote of a practical test of the soil, " you

SOIL-TEXTURE IN THE FIELD.

sprinkle a very little water upon a clod of it, and knead it with your hand."

Milton Whitney's method has found wide acceptance and is a most useful and rapid way of getting the same kind of information about the soil as would be obtained by making a mechanical analysis. In practice it is found that there is remarkable accuracy about this method of determination by handling, and remarkable agreement as to texture between different experienced soil surveyors in the computations which they make.

TECHNIQUE OF DETERMINING THE TEXTURE.

A technique for recognizing the different textural classes in the field has been worked out for the New Jersey system and can be adapted to other requirements. It is not always easy to convey in words an essentially practical procedure but here is an account of the principal features of this mode of recognition:—

From the surface of the ground take up a handful of the soil in a moist (not wet) condition, mould it with the whole hand and ask yourself three questions, or as many of them as may be necessary. Let us take the questions in turn:—

The first question: Is the soil gritty? By gritty is meant that sensation which is experienced when a handful of sand, such as seashore sand, is kneaded between palm and fingers. Is the soil gritty? Let us, in the first instance, presume that the answer is in the negative. Then let us pass on to

The second question: Is the soil silky? (i.e. has the soil the feeling that is imparted by handling silk fabric?). Again, presuming "No" to be the answer we ask

The third question: Is the soil sticky? For the

third time we shall presume that the answer is in the negative.

Thus, from our answers to three questions we have arrived at the conclusion that the soil is devoid of grittiness, silkiness and stickiness. There is one soil class, and one only, that gives this result on handling (as has already been indicated) and that soil is LOAM (13 in the list).

To return to *the first question:* Is the soil gritty? If our answer be "Yes," the soil is lighter in texture than loam. It therefore belongs to one of the first twelve classes in the New Jersey system. Then, as we handle the sample we note whether it soils the fingers. If it does NOT it falls into the group of the first four classes:—

1. Coarse sand.
2. Sand.
3. Fine sand.
4. Very fine sand.

Let us select the second class in the above list of four textures, Sand—the qualification "medium" is understood and it is, therefore, unnecessary to use it. Here, in "sand" the grains are of medium size and it is precisely by this character that we are able to identify .... 2. SAND.

If the grains are markedly larger than they are in (medium) sand we recognize the soil as

1. COARSE SAND.

In the case of the grains being smaller than they are in (medium) sand, the soil is fine sand or very fine sand. If the individual grains though clearly smaller than they are in (medium) sand are yet quite easily visible individually to the naked eye, we are dealing with a soil which we classify as ...... 3. FINE SAND.

If, on the other hand, the grains are only just visible individually to the naked eye, we have before us

4. VERY FINE SAND.

We have dealt with those four classes in which there is no soiling of the fingers on handling a sample, we have now to consider those gritty soils which do soil the fingers. Among these, some can be moulded into a cohesive ball, some cannot. If we cannot get the sample to form a cohesive ball it belongs to the second group of four textures:—

5. Loamy coarse sand.
6. Loamy sand.
7. Loamy fine sand.
8. Loamy very fine sand.

These, like the first four classes, are all alike among themselves except in grain size.

If the sand grains present are markedly larger than medium we have .... 5. LOAMY COARSE SAND.

Where the sand grains are medium the soil is

6. LOAMY SAND.

If the sand grains are smaller than medium, but are yet clearly visible to the naked eye, we recognize

7. LOAMY FINE SAND.

Where the sand grains are just visible to the naked eye, and no more, the material is

8. LOAMY VERY FINE SAND.

Gritty soils which can be moulded into a cohesive ball when just moist, belong to the third group of four textures:—

9. Coarse sandy loam.
10. Sandy loam.
11. Fine sandy loam.
12. Very fine sandy loam.

Once more these four classes are different from one another only in grain size:—

With coarser than medium sand grains the soil is 9. COARSE SANDY LOAM.

With medium sand grains ......10. SANDY LOAM.

With grains smaller than medium, but still clearly visible .... 11. FINE SANDY LOAM.

With sand-grains barely visible, individually 12. VERY FINE SANDY LOAM.

Then follows as already defined..........13. LOAM.

In the New Jersey system there follow:—

14. Silty loam.
15. Silt loam.
16. Silty clay loam.
17. Clay loam.
18. Clay.

Of these neither silty loam nor silt loam can be polished by pressing a sample of the soil in a moist, but not wet, condition between the thumb and forefinger, but both have a decidedly silky feeling when they are handled.

When the silky feeling is just recognizable, but there is very little resistance to the deformation of half a handful of the soil moulded into a little ball, the material is .... 14. SILTY LOAM.

When the silky feeling is quite obvious and there is considerable resistance to deformation (even to the point at which the experienced pedologist knows that the soil is about ready to take a polish) the soil is .... 15. SILT LOAM.

Each of the three remaining soils can be polished by pressing a sample in a moist, but not wet, condition between the thumb and forefinger.

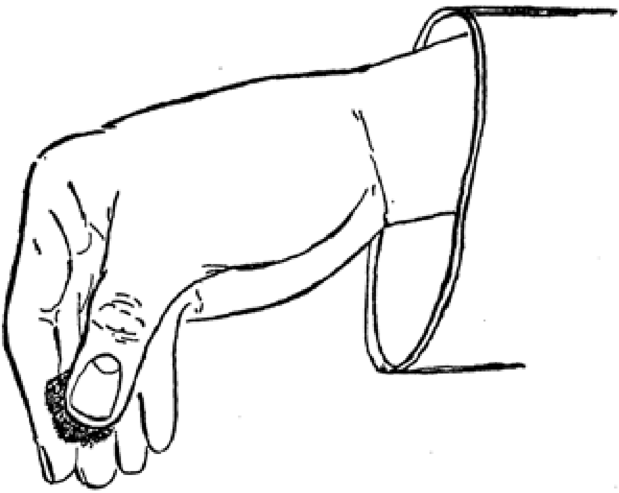


Figure 43. **Soil-texture.**
Pressing a small quantity of moist soil with a sliding motion between fingers and thumb to see if a polish can be induced.
Drawn by H.K.B.-B.

If resistance to moulding, while considerable, can be overcome without difficulty the soil is
16. SILTY CLAY LOAM.

Resistance to deformation begins to be difficult with
17. CLAY LOAM.

Resistance to deformation between the finger and thumb is exceedingly difficult in the case of . . 18. CLAY.

The information just given is sufficient with practice to identify all the textural classes in the New Jersey system, but the following key may also be convenient:—

A1. Soil gritty .... B
A2. Soil not gritty .... M

B1. Soil will not form a cohesive ball C
B2. Soil will form a cohesive ball .. J

C1. Soil stains the fingers .... G
C2. Soil does not stain the fingers . D

D1. Sand grains medium in size or smaller .... E
D2. Sand grains larger than medium COARSE SAND.

E1. Sand grains smaller than medium.................. F
E2. Sand grains medium in size.... SAND.

F1. Sand grains clearly visible to the naked eye .... FINE SAND.
F2. Sand grains only just visible individually to the naked eye VERY FINE SAND.

G1. Sand grains medium in size or smaller .... H
G2. Sand grains larger than medium LOAMY COARSE SAND.

H1. Sand grains smaller than medium.................. I
H2. Sand grains medium .... LOAMY SAND.

I1. Sand grains clearly visible to the naked eye.................. LOAMY FINE SAND.
I2. Sand grains only just visible individually to the naked eye LOAMY VERY FINE SAND.

J1. Sand grains medium in size or smaller .... K
J2. Sand grains larger than medium COARSE SANDY LOAM.

K1. Sand grains smaller than medium.................... L
K2. Sand grains medium .... SANDY LOAM.

L1. Sand grains clearly visible to the naked eye ....FINE SANDY LOAM.
L2. Sand grains only just visible individually to the naked eye VERY FINE SANDY LOAM.

M1. Soil silky or sticky .... N
M2. Soil neither silky nor sticky.... LOAM.

N1. Soil will not polish when rubbed between finger and thumb .. O
N2. Soil will polish................ P

O1. Soil just slightly silky .... SILTY LOAM.
O2. Soil markedly silky .... SILT LOAM.

P1. Soil excessively difficult to deform between finger and thumb .... R
P2. Soil not excessively difficult to deform .... Q

Q1. Soil resistant but deformed with comparative ease .... SILTY CLAY LOAM

Q2. Soil deformed with some difficulty .... CLAY LOAM.

R. .... CLAY.

CHAPTER IX

PUTTING A NAME TO A SOIL

There is a sense of satisfaction in having a good and distinctive name for anything. In agriculture we have names for our implements, our breeds of stock, our varieties of cereals, and so on. Pedology has given farmers—for the first time—names for individual soils. In these few pages, the way it is done is explained.

WE have previously seen that eight properties are employed in characterizing and establishing the *soil-series* and that two soils or more that are alike in all these eight points are classified in the same *soil-series;* and it has already been mentioned that in characterizing individual soils within the series, soil-texture is very important. As a matter of fact in naming the individual soil (the *soil-type* of the pedologist) the series name is used followed by the name of the soil-texture exhibited by the surface soil.

NAMING THE INDIVIDUAL SOIL.

We may take an example from the work of C. G. Stephens and J. K. Taylor, in Tasmania. The Huon soil-series is the most important and extensive described by them in dealing with the apple-growing soils of Tasmania, it " forms the backbone of the more prosperous settlements in southern Tasmania." The four soils (*soil-types*) of the Huon series are the Huon silty loam, Huon loam, Huon sandy loam, and Huon sand. It will be noted that each is named by uniting

the name of the soil-series with that of the textural class of the surface soil. These four soils " fall into a neat group distinguished by the descending order of silt and clay content of the surface and sub-surface soils. The sub-soils are uniformly heavy clays, with the exception of that of the Huon sandy loam, which falls into the medium clay group."

Having characterized and named a soil-type, we shall naturally expect it to exhibit, in different places where it occurs, minor differences of depth, of stoniness and so on. When such minor variations are of sufficient importance to affect the economic value of the land but not sufficient to give the soils the characters of another soil-type, they are regarded as *soil-phases* and may be mapped as such. In descriptions the peculiarity upon which a phase is based (*shallow* phase, *gravelly* phase, *rocky* phase, etc.) is mentioned.

VARIATIONS WITHIN THE SOIL-TYPE.

It may be of advantage to students who have a knowledge of biology to draw attention to the fact that we may compare closely a *soil-series* with the genus in biology, the *soil-type* with the species, and the *soil-phase* with the variety.

The classification of the soils of a region into *soil-series* (genera) *soil-types* (species) and *soil-phases* (varieties) results in the recognition of a large number of different kinds of soil. It must be remembered that whether we classify them or not those many different kinds of soil are there all the same, and if we are going to make the best possible use of our soils we ought to know those very things which such a classification will reveal for us. Doubts and fears have been implied and expressed about the multiplicity of *soil-series*, and expedients have been suggested

A MULTIPLICITY OF SOILS.

to reduce their number by some sort of combination. However, our modern attitude of mind towards the soil, in regarding it as a natural object, implies the individuality of a very large number of soil-units, the soils. It is no new experience in the study of nature to encounter a large number of units. In chemistry large numbers of substances are known, but no chemist would suppose it expedient, on that account, to call two different substances by the same name to reduce the complexity of this diversity. It is true in biology; for example, there are over 3,000

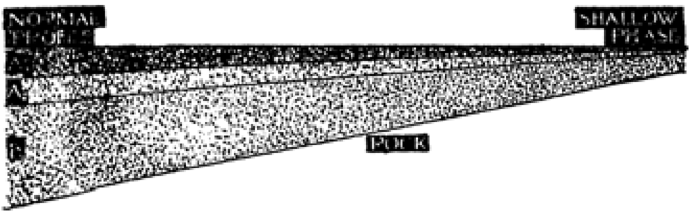


Figure 44. *SOIL-TYPE* and *SOIL-PHASE*.
At the left of the diagram the normal profile of a *soil-type* is shewn; to the right the horizons become shallower to produce a *shallow phase*.
Drawn by S.G.B.-B.

species of beetles in the British Isles; but no entomologist would suggest that, in order to avoid confusion in speaking of them, three or four species should be combined and called by the same name.

In the case of soil studies there is no reason from experience to fear the establishment of a large number of readily recognizable units, especially when we remember the object of this system of naming our soils, which is their recognition again, wherever they may occur. Another point in this connection which it is well to bear in mind is that within the

experience of the individual farmer it is unlikely that any extremely large number of *soil-series* will occur. It will only be when we take a very extensive area, or a country as a whole, that we shall meet with this large number of *soil-series*, and then it will be comparable with large numbers of kinds of other natural objects in every branch of study, minerals, rocks, fossils, geological strata, plants, animals, chemical substances, for wherever they are studied these great assemblages of different recognizable units are matters for the specialist, to whom fine distinctions in remote fields of study must always be referred.

CHAPTER X

FINDING THE BEST CROP FOR EVERY SOIL

We have seen how soils originate. We have found great variety among the individual soils of the soil-mantle. No soil is suitable for every crop. There is a natural wild vegetation for every soil. How can the farmer imitate this compatibility between plant and soil for his own purposes? How can he make the best use of his soils or find the best soil for a crop he wants to grow? These are big questions, but the lines along which they may be answered are indicated in this chapter.

THE examination of a single farm, as we have seen, often reveals the presence of a number of "soils" (as the farmer terms them). These are the *soil-types* of the pedologist. As we extend the area of examination we naturally meet with an increased number of *soil-types*, so that by the time a whole region has been properly surveyed we may expect to find quite a large number of them. It is generally recognized that some plants will grow, at least in a fashion, in almost any soil. There are others that are most fastidious. In the United States a great deal has been done to correlate crop-plants and soils (soil-types). This work first entails the examination, naming and description of every soil-series. Individual soil-types can then be mapped. As soon as the distribution of the soils is thus recorded, correlation between

SOIL UTILIZATION.

the soils and successful crops can be made. It becomes possible to pool information previously obtained by individual farmers. They have information about the response of their own soils to particular methods of cultivation, manuring and cropping. The establishment of soil-series and soil-types and the preparation of maps makes it possible to give wide publicity to the accumulated knowledge. As far as Great Britain is concerned there are immense possibilities for useful development along these lines. Something has already been done especially in the case of fruit trees.

NATURAL VEGETATION.

Visualize the soil in its virgin state. The natural vegetation established in an area is determined in part by the soil and in part by the climate: these three, vegetation, soil and climate are closely interdependent. It is fully recognized that some virgin soils, from one or more of their natural properties, are particularly favourable to one plant or a group of plants. To put it another way, each plant has its own most suitable and most favourable soil, the plant itself has its effect upon the kind of soil produced; so has the climate; the climate not only affects the growth of plants, but the kind of plant-cover that occurs in a region has its effect upon the climate, so that the whole set of inter-relationships is quite complicated.

MAN'S CULTIVATED PLANTS.

It is not, therefore, surprising to find, when we come to consider man's cultivated plants, that each farm crop has its own most suitable and most favourable soil. Farming is a business and the good soil is part of the farmer's stock-in-trade, and, being a business man, he naturally wishes to put his soil to the best and most profitable use. This can be done not by being satisfied to grow any crop

that will give a margin of profit however small, but by growing the most suitable crops on the different soils of his farm. Looking at the country as a whole, we want to be able eventually to direct every farmer who wishes to grow a particular crop to places where it is known that the best soils for that crop occur, and, on the other hand, to be in a position to say which are the best crops to grow on any particular soil that a farmer may happen to have on his farm. We aim at finding the best soils for every crop and the best crops to grow on every soil; it is an aim which has been virtually attained in the state of New Jersey.

FRUIT-GROWING AREAS.

As far as our own country is concerned, we may consider what has been done in the fruit-growing areas on the Lower Greensand rocks of Kent. Here Bane and Gethin Jones have listed 26 soil-series, and this must include about 80 individual soils (*soil-types*). Dealing with each series separately these authors indicate a number of soil properties, including the texture range of the surface soil, and a note is made in each case of the growth shewn by fruit crops. In this particular instance a great deal of valuable information has been assembled and is made available for the guidance of fruit-growers in the area mentioned. By way of illustration we may take the Elmstone series, which is included in the survey. On these soils, growth shewn by fruit-trees is good to very good. Of eighteen instances of the growth of fruit on this *soil-series* only two were below the average and both of these suffered from bad management; fourteen of the eighteen were above the average. Apples, plums, sweet cherries, gooseberries and black currants are the fruits considered and all do well.

The Elmstone series occurs where landslides have carried large quantities of rag and hassock (materials composing the Hythe Beds of the Lower Greensand rocks) down the escarpment, so that a mixture of debris has collected to a considerable depth, even to more than 20 feet, over the Atherfield Clay. Sometimes the landslide has swept up and incorporated in the debris some of the Atherfield Clay itself with a result that a heavier texture has been imparted to the resulting soil. Where three feet or more of such debris covers the Atherfield Clay, the soil belongs to the Elmstone series. The colour of the surface-soil is a rather dark greyish brown. Owing to their depth and topographical position on the slopes of the escarpment, the soils of this series are well-drained. Typical soil-profiles shew 9–12 inches of rather dark greyish-brown loam or heavier surface soil: below this occurs a fairly uniform rather pale brown material; ragstone, chert and flint generally occur throughout the profile. The soils are alkaline.

The information thus presented is sufficient to justify the soil-scientist in recommending soils of the Elmstone series wherever they occur as highly satisfactory for the growth of the fruits that have been mentioned. One note of warning might be sounded to the effect that a wet *phase* has been observed, and this was associated with an especially severe attack of Apple Canker on Allington Pippin. This exceptional occurrence helps to emphasize the importance of field observations and quite local conditions when considering the relation of soil and plant.

Of course, it is possible in the absence of sufficient information about the distribution of the individual soil-types and soil-series in this country, to approach the question of soil utilization from the opposite

direction and to ask about the soil requirements of any particular plant. It is not merely an enquiry as to where a crop can be made to drag out a lingering existence from seed-time to harvest, irrespective of the return which the farmer may expect; it is rather a question of finding the optimum (the best) conditions for any plant grown for profit, whether it be the great forest tree or the humble carrot. Let us take these extremes. First consider three examples from silviculture; the Ash will grow in some fashion on almost any soil, but where the ground is wet you cannot get good timber. Beech hates heavy or wet or acid soils. Pines flourish on podzols (see page 219); they are their natural soils. Then about the carrot; it is a fastidious plant. It needs a deep open soil not heavier than loam and deep cultivation is essential. It is known that well-branched tap-roots of the carrot reach to a depth of more than seven feet and probably extend much deeper.

PLANT REQUIREMENTS.

We have now followed the subject of soil utilization far enough to indicate that it is open to the forester, gardener, or farmer to consult the soil-scientist, or to judge for himself from his own observations and knowledge whether any of his own soils really provide the best conditions for the growth of any crop in which he is interested, or, on the other hand, to enquire which crops are best suited to the soils of his farm from the point of view of such properties as depth, water conditions, chemical reaction, topography, and texture. In passing, we may point out that a great deal of emphasis will often be found to have been laid fifty or a hundred years ago upon texture, sometimes to the exclusion of other

THE PLANT AND THE SOIL.

properties which are quite obviously of much greater importance.

GOOD MANAGEMENT.

By no means the least important part of good management in farming lies in providing each soil with the range of plants best suited to its natural properties and adjusting artificially such factors as plant-foods which are to a very considerable extent under the control of the farmer. We are not here concerned with such questions as the proximity of markets, availability and cost of transport, prices of manures, and so on, which the farmer as a business man will naturally take into account when deciding what crops he will grow.

Let us look briefly at the soil requirements of a few of the crops commonly grown by English farmers.

Corn Crops.

WHEAT.

Wheat requires plenty of moisture but its seedlings suffer in winter if they are subjected to water-logging. If, however, a deep rooting system can be established it can withstand periods of very dry weather. In soils that allow of its development the mature root system of winter wheat may well extend over six feet into the ground, and on occasion there is still deeper penetration. Moisture in the deeper layers of the soil is very important for the maximum development of the plant. Neutral or slightly alkaline soils suit it best. It is generally grown in this country on the heavy soils of our drier districts. In accord with its moisture requirements wheat will grow satisfactorily in wetter districts on lighter soils.

Barley has a very adaptable rooting system but

is intolerant of acid conditions. It likes a well-drained soil. It can succeed in rather shallow free working calcareous soils, such as chalky loams in which, owing to lack of deep penetration, the roots have a very generous and efficient lateral spread.

BARLEY.

If barley is grown in a deep fertile soil its roots may extend to a depth of more than six feet, with the uppermost three feet, or a little more, with many roots actively absorbing water and mineral foods. In such a case the lateral spread of the roots may be as much as a foot all round the plant. You will find barley described in books as a shallow-rooting cereal, but that is only true where shallow or dry soil prevents full development of the roots. The quality of the grain is often best when root-development is adequate but somewhat restricted.

Oats succeed in the cooler, damper parts of the British Isles, and stiffer soils seem to suit this crop best. It will flourish in a wide variety of soils, but fair drainage is desirable, especially for autumn-sown varieties. It is the most suitable cereal for fenland.

OATS.

Root-development depends upon the texture and moisture conditions of the soil. A depth of four feet is not unusual with a lateral spread of six to eleven inches all round the plant, the main development of the system being found in the upper 2½ feet of the soil. Lack of water may confine the roots to the top 2 feet of the soil, but in a deep mellow loam the system may extend to a depth of more than six feet; it is then to be expected in two parts, a widely spreading network in the surface six or eight inches, and a deeper part less profuse. Oats will grow well in very acid soils.

BEANS.

Heavy non-acid soils in which, however, a good seed bed can be prepared, well-pulverized and firmly packed, are very suitable for beans. The plant has a widely spreading root-system which is very adaptable to the condition of the soil.

PEAS.

Peas like an open well-drained, fairly light, non-acid soil. The moisture requirement is high. The root-system may be expected to reach a maximum depth of over three feet, with a spread of two feet in all directions around the plant. The bulk of the root network will be found in the top two feet of the soil.

Forage Crops.

CABBAGE.

Cabbage (including Kale): This crop which has many varieties will grow satisfactorily on a great variety of soils. Its roots recover well from the injury of transplanting, and the root-system eventually developed is powerful and capable of obtaining food even from a very heavy soil. It may have a lateral spread of as much as 3½ feet all round the plant, and there may be a well-ramified profuse network of absorbing rootlets down to five feet. Maximum depths may exceed seven feet. Moisture and manure are important requirements.

MANGEL WURZEL.

Mangel Wurzel is a sun-loving crop which will grow very satisfactorily on heavy land, though it is not fastidious in the matter of soil. It is deep rooting. It does not do well under wet and cold conditions.

TARES.

Tares (Vetches) are for use in May and June in the south or later in the north of Great Britain. These will flourish in a wide range of soils, though heavy land rich in lime is probably the best for their growth.

TRIFOLIUM.

Trifolium (*Trifolium incarnatum*, Crimson or Scarlet Clover) is for use in May and June. This crop needs a firm seed bed. It is intolerant of acid conditions. It cannot stand too much cold and wet, and is therefore grown particularly in the southern part of this country. Tap roots may extend down to 4½ feet.

SWEDE AND TURNIP.

Swede and Turnip: For these crops it is important to have a moist soil which can be cultivated easily and kept free from weeds. For this reason, lighter soils are generally to be preferred. A fine tilth is needed for good germination. The tap-root of the turnip will grow more than an inch a day during the first few weeks, and the root system eventually becomes very profuse and may have a lateral spread of 2½ feet all round the plant, and go down 5½ feet into the ground. Swedes and turnips do well in a cool, moist climate where there is little sun.

OTHER CROPS.

SUGAR BEET.

Sugar Beet is a deep rooting plant with a very fleshy tap-root. The ideal soil is a deep friable loam with a comparatively high lime content. In such a soil the surface foot may be expected to have a root-system of profuse, widely spreading and much branched

growth, and a more vertically penetrating part going down to six feet or so with extensive ramification in the deeper soil. The root is susceptible to differences in soil environment caused by variations of water content and fertility and a well-drained soil is required for success. If there is ample rain in spring the deep-rooting habit will enable the plant to survive drought later in the year, though there will then be a tendency for the yield to be reduced.

POTATOES.

Potatoes have a more superficial root-system than many crops, so that a mellow free working loam, or something lighter, under conditions of moderate rainfall are very suitable. In early growth the roots are confined to the top eight inches or so, and perhaps after extending outwards for as much as two feet the roots will turn rather sharply downwards and penetrate to three feet or a little more. There is a famous soil developed over the Old Red Sandstone, near Dunbar, which produces magnificent potatoes, very much better than those grown from the same seed on other good potato soils, so that there is no doubt about the importance of soil in its effect upon quality in this crop. As a matter of fact, most soils in this country will grow potatoes after a fashion, though heavy wet soils are totally unsuitable because free drainage and free working are essential.

PASTURE.

There can be little doubt that a deep loam, or silty loam, with satisfactory moisture conditions is the best for permanent pasture. The Finn loam and Finn silty loam, which occur in Romney Marsh, support the best and most famous fatting pastures in that renowned district. The principal characteristics of these

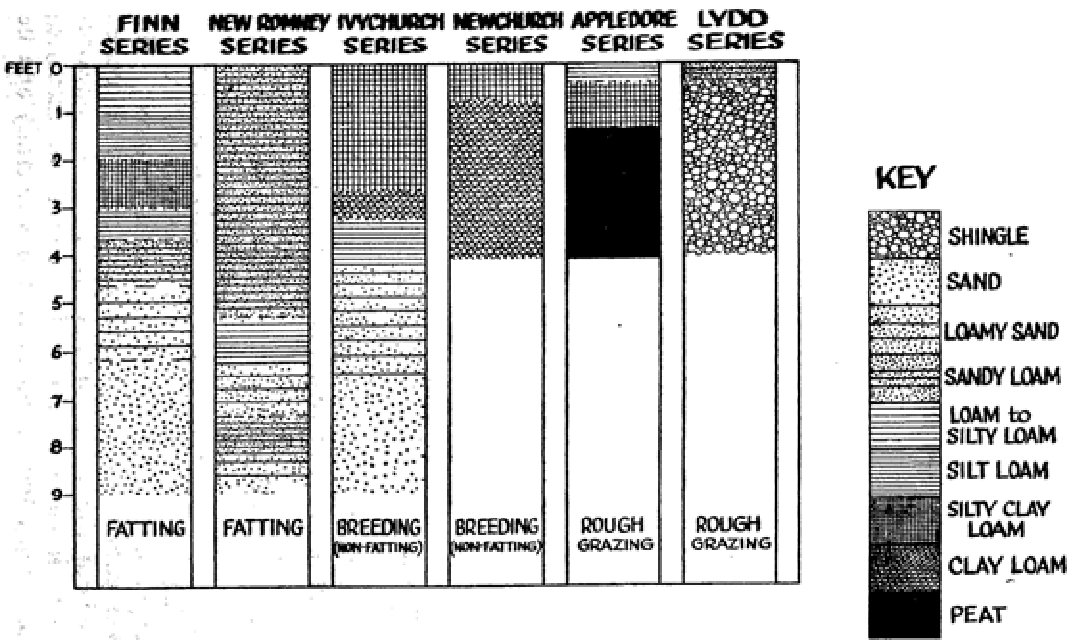


Figure 45. **Soils of Romney Marsh.**
Profile differences of texture are here diagrammatically shewn.
Courtesy of L. W. Leyland Cole and Dr. J. K. Dubey.

two soils have been investigated by Cole and Dubey. There is a surface horizon of 10 to 20 inches of brown loam or silty loam, typically followed by 12 to 16 inches of silt loam with orange mottlings, then by four to six inches of silty clay loam containing a slight deposit of iron compounds. This is followed by sandy loam which becomes lighter in texture with depth. The soil easily draws up water in summer to maintain a vigorous growth of the grass. The soil is alkaline in reaction and alkalinity increases with depth. The suitability of such soils for the support of permanent pasture is sufficiently indicated by the fact that their grazing will fatten six to ten sheep to the acre in summer, no mean performance.

MARKET GARDENING.

It has been pointed out in the Key volume of this series of books that all market garden crops need a deep soil in good heart, while efficient cultivation and manuring are essential to success. This is well illustrated by the carrot, some varieties of which may also be grown on the farm for the feeding of stock. The carrot is characterized by a deep tap-root system, strong and well-developed. A maximum spread of roots for more than 2¼ feet all round the plant may be expected in a loose fertile soil. There may be well branched tap-roots to a depth of more than seven feet. A good depth of light soil in a friable condition and free from stones is clearly necessary for the adequate development of the roots and, for the same purpose, a fairly high rainfall is required. The market gardener needs a soil that can be cultivated throughout the year, without hindrance by unworkable conditions after rain. His culture is intensive; he can supply the necessary manures liberally and he

must cultivate deeply. Consequently a soil as light as that upon which heaths normally grow will often make for very successful market gardening if an adequate water supply is provided. If similar soils occur in valleys and the water-table is sufficiently high, that is an additional advantage; or where alluvial or colluvial materials from light textured rocks, such as sands and sandstones, have accumulated to a considerable depth and have been mixed with rather heavier ingredients, excellent conditions of depth, workability and available absorbed water are frequently present for the success of the enterprise.

FRUIT-GROWING.

Clear correlation has been observed between soil conditions and fruit-tree performance and much detailed valuable information is available. In general terms the most suitable soils for fruit are those which readily absorb rain and readily yield it up to the plant in dry weather. Soils in which the natural drainage is very impeded are not suitable for fruit-growing nor are those that are excessively drained; both are associated with poor tree growth. Soils which are neither ideal nor absolutely unsuitable have been employed satisfactorily under able management, for certain forms of fruit-growing. In such instances the general aim is the correction of water conditions. Where there is excessive moisture in winter, drainage is improved; where the available water in summer is inadequate improvement is effected by manuring.

The instances taken in this chapter do no more than indicate general lines along which the grower may proceed in the selection of soils for his crops. No experienced English agriculturist with a good

RESEARCH NEEDED.

knowledge of plant requirements and of soil capabilities, as far as they are at present known, will be able to give much detailed information under this head except in the case of fruit-growing. Much work still lies ahead of the agricultural pedologist in this field of research, but it is one which should in the end bring much profit to the nation. There is national wealth in the right use of every soil.

CHAPTER XI

SOIL-EROSION

In this chapter the different kinds of soil-erosion are defined and discussed. Examples of erosion in this country are mentioned. Measures of control are indicated.

> "The prevention of soil erosion is now recognized as being one of the most important agricultural problems with which the cultivator in many parts of the world is faced."
>
> T. EDEN, in *Soil Erosion.*

A MENACE TO AGRICULTURE.

WHEN soil is eaten away by natural agencies the phenomenon is known as soil-erosion, and since it is, of course, greatly to the detriment of agriculture and horticulture, its destructive importance has been forced upon the notice of farmers in many parts of the world, as for example in Canada and the United States, in Ceylon, Nyasaland, and Java. Sometimes agriculturists and governments have neglected measures to combat the menace with disastrous results, but the importance of the problem is now fully recognized and means of control are widely practised.

There are three clearly defined kinds of soil-erosion:

(1) Wind-erosion.
(2) Sheet erosion by water.
(3) Gully erosion.

A number of factors determines the occurrence and severity of soil-erosion. The absence or paucity

of plant-cover for the land and the occurrence of uncompacted soil are important as causes of all kinds of erosion. Erosion by water is aggravated by (i) increase of declivity, (ii) a tendency for the occurrence of periods of excessive precipitation or rapidly melting snow, so that the effect of much snow or a heavy rainfall, say, in winter, or thunderstorms in summer, make great rushes of water suddenly available for removing soil, (iii) the impervious nature of underlying rock, because with impervious rock absorption of water after heavy rain is inadequate to prevent damage.

Exposure of the site to wind action and the prevalence of frequent high winds subject soils not covered by plants to wind-erosion, and if the soil is light in texture or the rainfall low there is still greater risk of damage from this cause.

The number of particles of dry soil removed by the action of wind may be so small as to be negligible; on the other hand the quantity may be so great that the land is greatly depleted.

WIND-EROSION.

Bennett and Lowdermilk mention a case of dust carried hundreds of miles to show that the wind exercises a selective action upon the constituents of the soil, the lighter more fertile particles being transported a very long way, the heavier and less fertile particles being caused to " skip and roll along the surface until they pile up in drifts behind obstacles." The instance cited by these authors is that of a dust storm which occurred early in 1937. It originated in the Texas-Oklahoma Panhandle country and, after having travelled in a north-easterly direction over five States, passed on into Canada. Soil material deposited by the storm on snow at Clarinda, Iowa, was compared with samples taken from a small dune deposited

in the same storm near Dalhart, Texas. "Analysis showed that the dust carried a distance of more than 500 miles, contained ten times as much organic matter, nine times as much nitrogen, and nineteen times as much phosphoric acid as the dune sand piled up in the general locality of the storm's source." The table gives the particulars of these analyses. "The transported material was also of much finer texture, containing no sand as against more than 90 per cent. sand in the residuary, drifting dune left behind."

TABLE.

CHEMICAL AND PHYSICAL ANALYSES OF VIRGIN SOIL, DUNE SAND, AND DUST DERIVED FROM CULTIVATED SOIL AS THE RESULT OF A DUST STORM ON AND PRECEDING FEBRUARY 6TH, 1937.

COMPOSITION	Grassland near Dalhart, Tex. (virgin soil profile)	Sand dune near Dalhart, Tex. (formed on and immediately preceding Feb. 6, 1937)	Dust, near Clarinda, Iowa (collected from surface of snow, Feb. 8, 1937)
	Per cent.	*Per cent.*	*Per cent.*
Organic matter .	1·06	0·33	3·35
Nitrogen . .	·06	·02	·19
Phosphoric acid .	0·4	trace	·19
Potash . . .	2·05	1·77	2·58
Sand (coarse, medium fine and very fine)	79·2	91·8	·0
Silt and clay (diameter, silt—0·05–0·005 mm., clay—0·005–0 mm. .	19·6	7·5	97·0
Ultra fine (colloid diameter 0·002–0 mm.) . . .	8·1	5·2	33·4

Although this kind of erosion is of especial importance under conditions of very low rainfall, it must not be forgotten that it can operate even in Britain. Mr. Furneaux has told me of his seeing a striking instance in Lincolnshire. Soil swept from a field of sugar-beet was banked up against the stems of plants at the edge of an adjacent cereal crop to the height of some 18 inches. He knows of a farmer in the Fens who had to drill sugar-beet as many as five times as a result of wind-erosion.

Mr. D. V. Fletcher has informed me of a remarkable example of wind-erosion which occurred some thirty years ago on his father's farm near Thirsk, in the North Riding of Yorkshire. After heavy rain the surface soil of an arable field of 12 acres of sandy loam had formed a crust—as is not unusual in such cases—and with mistaken zeal the field was afterwards rolled. The result was that about two inches of soil thus broken and loosened blew off the whole of the twelve acres so that an adjacent sunken road (in places normally twelve feet below the surface) was almost filled up and rendered impassable.

I am greatly indebted to Mr. J. H. Stapley of the School of Agriculture, Cambridge, for the following account of the trouble:—

Some years in the Eastern Counties certain areas of agricultural land are subject to "blowing," or erosion by wind. When this occurs the surface soil is swept up into the air creating a dust or a cloud which can be seen for several miles away. Blowing occurs in certain districts where the soil is light and easily lifted by wind. Such areas are to be found in the black fen, and in regions of light sandy soils. Any areas in the black fen are liable to wind-erosion but it is especially noticeable in the localities near Feltwell, Norfolk, southwards down to Lakenheath,

Suffolk, where the peat of the fen meets the sand of the " Breckland." Similar mixtures of peat and sand occur elsewhere, such as in the region of Cottenham, Cambs. Light sandy soils subject to blowing occur in West Norfolk on the high ridge from King's Lynn up to Holme-next-the-Sea, the area around Sedgeford being particularly so. In Cambridgeshire the strip of Greensand near Gamlingay suffers quite frequently. The " Breckland " area, which covers 400 square miles within the region bounded by Mildenhall (West Suffolk), Swaffham (Norfolk), Wretton (Norfolk), Thetford (Norfolk), and Bury St. Edmunds (West Suffolk) is a barren area agriculturally, being a pall of sand overlying other formations chiefly Chalk. Land in this area is subject to continual wind-erosion, especially the heaths (e.g. Lakenheath Warren, Palmers Heath, but this has no agricultural value). Some arable land is also liable to erosion.

There appear to be three conditions which predispose land to blowing. These are—

1. Lack of binding material, clay or humus, in the surface soil.
2. Lack of rain so that the surface soil dries out readily.
3. Level surfaces and absence of windbreaks.

The final condition which leads to erosion is, of course, wind of sufficient velocity. Wind velocities recorded at Cambridge during some of the worst blows did not exceed 35 miles per hour, although this would probably be lower than the velocities experienced in the open country. Means of measuring such velocities were not available. No particular wind direction seemed to predominate.

With regard to the above conditions the black fens contain practically no clay in the regions where

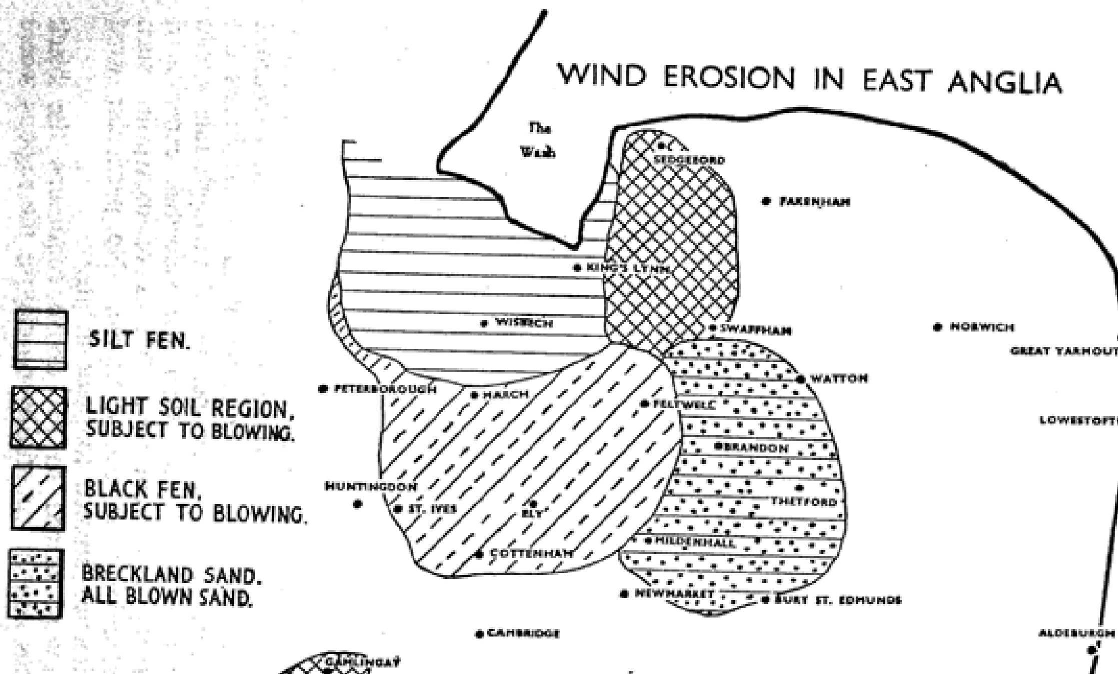


Figure 46. Wind Erosion Map of East Anglia. *Courtesy of J. H. Stapley.*

blowing is most common. From analysis, such soils are found to contain over 50% sand. Although black fen soils contain abundant organic matter, they are frequently very short of humus, the organic matter occurring as fine powder. The sandy soils contain up to 90% coarse sand, and generally over 50%. Erosion does occur, however, on the Western borders of the fen district in Huntingdonshire, where the peat of the fen meets the Oxford clay of the highlands.

That rainfall in the early months of the year is of importance is shewn by the following particulars covering the last nine years, when serious blowing occurred.

Erosion June 7th, 1935—Dry spring period with cold weather up to mid June.
No erosion, 1936—Very wet spring.
No erosion, 1937—Plenty of spring rain.
No erosion, 1938—Fine March and spring-like, but no wind.
No erosion, 1939—Wet March and April.
No erosion, 1940—Strong winds in early April, but soil wet.
Erosion, April 25th, 1941—N.E. Unusually dry spring.
Erosion, April 28th, 1942—N.E. Strong winds early April, but no rain.
Erosion, May 25th, 1942—S.W. No rain in May.
Erosion, April 7th, 1943—N.W. } No rain February and March.
Erosion, April 26th, 1943—N.W. }

When blowing occurs it is usually in April or May—the season is remarkably constant. Once the soil has dried out before the crops cover the ground erosion is liable to occur.

The absence of windbreaks is the common feature of the fen districts, and undoubtedly influences the liability of these regions to soil-erosion. The fen

districts by their nature are quite flat. The light soils which most commonly blow are situated on high ridges completely exposed to winds.

Blowing causes most damage on agricultural land where the surface has been reduced to a fine seed-bed for crops such as sugar-beet, flax, and turnips, and finished off by being rolled flat. On fields so treated blowing is frequent, the surface soil being swept off to a depth of three to four inches and piled up in the ditches or drains. Although the subsequent blockage is in itself a serious matter the worst damage is the actual removal of the crop plants bodily from fields. Whether it is possible for plant pathogens to be carried on wind blown soil is an important consideration. The sugar-beet eelworm, discovered in England for the first time in 1934, has been found in many of the Fen districts where blowing occurs. Cysts, or the resting stage of the eelworm, in the soil, are undoubtedly carried about in this way. It is quite likely that an infected field may infect neighbouring fields during soil blowing. It is undoubtedly a major problem in reclaiming derelict Fen areas and bringing them into agricultural production, to decide how to introduce sufficient clay to bind them, once the natural vegetation has been removed.

SHEET-EROSION.

The removal by water of a more or less uniform depth of the surface soil over a considerable area is termed sheet-erosion. By careful observation you may frequently see evidence of this in a mild form in English fields. On ploughland it is widespread; it is common for example, in the High Weald of Kent and Sussex, and where the furrows run up and down the slope there may be a serious loss of the soil from the upper part of the field; the normal heavy rains of winter carry the soil down, and it accumulates at

the bottom of the field. The stratification of such deposits indicates clearly that each heavy rain brings down its quota to swell the material at the bottom of the slope where it can make but little contribution of value when the soil is already deep.

In many parts of the world sheet-erosion is an extremely serious problem and has led to great loss in the value of agricultural property.

GULLY-EROSION.

When topographical features or man's methods of cultivation favour the development of a clearly-defined course for the downward rush of water after a period of heavy rain and especially after a storm, gullies are cut deep into the land, and they grow wider and wider as a result of their use by flood waters. The fact that this gully-erosion presents serious problems for the farmer upon whose land it occurs is emphasized thus by the Tennessee Valley Authority, quoted by R. H. Walker and P. E. Brown:—

> Hordes of gullies now remind us
> We should build our land to stay,
> And, departing, leave behind us
> Fields that have not washed away;
> When our boys assume the mortgage
> On the land that's had our toil,
> They'll not have to ask the question
> "Here's the farm, but,
> WHERE'S THE SOIL?"

Cases of gully-erosion are sometimes met with in Great Britain as, for example, in an instance brought to my notice by Mr. Basil S. Furneaux. A thunder-shower near Horncastle, Lincolnshire, in April, 1939, resulted in the gullying of a field of winter wheat on Chalk to a depth of about a foot (see fig. 47). In this case a great mass of washed flints was spread out as a fan at the foot of the gulley. Near Paddock

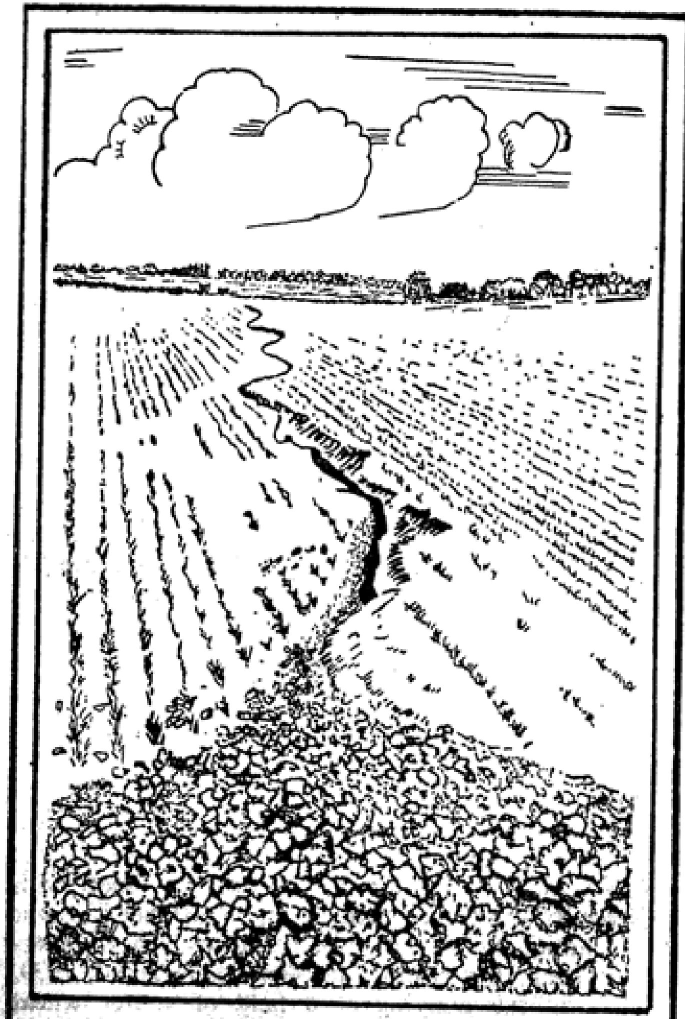


Figure 47. Gully-Erosion

near Horncastle, Lincolnshire, April, 1939. Damage after a thunder-storm. The crop is winter wheat; in the foreground is a mass of washed flints brought down by the storm. The gully is about a foot deep.

Drawn by S.G.B.-B., from a photograph by Basil S. Furneaux.

Wood, Kent, Mr. Furneaux photographed an example of gullying in an orchard in the spring of 1939; in this case the soil was a fine sandy loam developed from Tunbridge Wells Sand. The damage had occurred as a result of the heavy rains of the previous winter acting upon clean cultivated land. The phenomenon is very common in such soils.

Because all the types of soil-erosion that we have considered are initiated only where there is an absence of an adequate plant growth, combative measures include the clothing of the soil with vegetation as quickly as possible. Where climatic and soil-conditions favour soil-erosion every effort should be made to avoid leaving the soil long without a covering of plants. In places where the trouble is severe it is recommended that strip cropping should be practised. This means that two or more crops are grown side by side in such a way that the soil of the whole area that they jointly occupy is never left all bare or sparsely covered with plants. When one strip is being ploughed a good growth protects the one adjacent, and the whole cultivated area is never completely devoid of protection against the destructive action of wind or running water.

MEASURES FOR THE CONTROL OF SOIL-EROSION.

A number of farming practices are also advocated to mitigate the risks of erosion while the soil is completely bare or before the crop has grown sufficiently to be a proper defence, or in case a crop gives little protection at any stage of its growth. Instead of ploughing directly up and down hill or even following slight gradients ploughing is carried out along the contours. The ridges and furrows then lie across the path of the downwash and act as traps for the water. In the United States the efficiency

of the furrows as obstacles to the rapid run-off of the water is increased by the employment of an implement called a lister, either alone or in conjunction with a basin-forming attachment. The lister is an implement for setting seed. Its essential front part is a double mouldboard which throws the soil both ways and so forms a broad furrow or trench. In the case of a maize lister, seed is delivered into the trench or furrow from a hopper through a seed-tube which comes down to the ground behind the mouldboard. Two obliquely arranged discs are the hindermost essentials of the implement; they follow the seed-tube and cover the seed with soil. Sometimes the machine is provided with a basin-forming attachment. This automatically produces an earth dam across the furrow at intervals throughout its length: the dams help considerably to retard the flow of water and after rain result in the formation of a series of little pools from which the water soaks away gradually into the ground instead of sweeping downhill to spread havoc and destruction to crops and soil alike.

Another efficacious expedient for combating soil-erosion is terracing. Mention may be made of two kinds of terraces—both being ridges across the direction of the slope. One is designed to intercept the water as it runs down the gradient so that it can be absorbed by the soil. The other is to form a barrier in support of a drainage groove which carries the water slowly downhill into some regular drainage channel. The absorption terrace is a level ridge made along the contours by removing soil both above and below the site of the ridge and piling it up so as to intercept the water. The drainage type is made by cutting a channel which slopes very gradually downhill and building up the removed soil to form a low flat ridge on the downhill side of the excavated channel.

IN THE BRITISH ISLES.

Let it not be thought that because, in the British Isles, the depletion of the land by soil-erosion is seldom spectacular, it is of little moment to the farmer and the gardener. It must always be remembered that though the natural forces that cause this damage frequently produce but small results when their work is measured by the month or the year, yet, from the fact that they act continuously over a long period which is to be reckoned in decades and centuries, the sum total of their operations is a serious loss, not only to those engaged in the business of agriculture, but also to the nation itself.

The dust is gold that bears the harvest;
Save the soil that grows our bread;
Let not wind and rain remove it,
Guard with care for years ahead.

CHAPTER XII

THE PROCESSES OF SOIL DEVELOPMENT

The many different soils in which man grows food for himself and his animals originate by a number of soil-forming processes. Some account of these is given here.

SOIL-FORMING PROCESSES.

THE natural processes by which soils are produced (pedogenic processes) are, of course, extremely complicated, but it is possible to recognize certain lines along which soil development is constantly taking place and, with advantage to a clear understanding of the way in which different kinds of soils are formed, to consider those lines individually as isolated links in the chain of events which has resulted in the present world distribution of soils, which we may call the soil-pattern of the globe.

From what has been said elsewhere in this book it will be sufficiently realized that CLIMATE is very important in determining the kind of soil that is produced in any particular region. Since it takes a very long time—to be measured in centuries or even in thousands of years—for the development of a mature soil, changes of climate, however slow, are also very important. No climate is permanent, and the student of the soil must learn to regard the changing of climate as a drawn-out process which may transmute one kind of soil into another.

When all conditions are favourable, and especially when the rainfall is high enough for compounds of aluminium and iron to be washed down (leached)

into the ground from the upper horizons of the soil, so that those substances are accumulated at a deeper level, the process is called *podzolization*. In a broad sense the soils produced are Podzols. In the cooler regions of the globe the Podzols are characteristically grey. Their upper horizons, being depleted of compounds of iron and aluminium, tend, in such situations, to have a greyish tinge at the surface, and sometimes (in typical Podzols) an ashy-grey horizon not far below the surface. In very hot countries Podzols with a reddish or yellowish surface soil are to be found; below the surface such soils shew the same unmistakable signs of depletion which characterize the grey Podzols of cooler climates. In these soils of the tropics podzolization has had full play.

PODZOLIZATION.

In areas of low rainfall there is a tendency for water, by evaporating from vegetation and from the surface of the ground, to draw up other water from below to replace it. Water drawn up through the soil in this way is frequently found to contain dissolved calcium bicarbonate which has generally been obtained from the rock below. As this water approaches the surface carbon dioxide is given off from it and insoluble calcium carbonate is deposited as an accumulation in the soil. In addition, some of the calcium brought up combines with the colloidal substances in the soil and this tends to produce the physical effect of giving a granular structure to the clay present.

CALCIFICATION.

The addition to the soil of calcium carbonate (often loosely termed *lime*) is called calcification. The addition is sometimes soft, sometimes hard; sometimes it forms a continuous layer or "pan," at other times it is present as concretions.

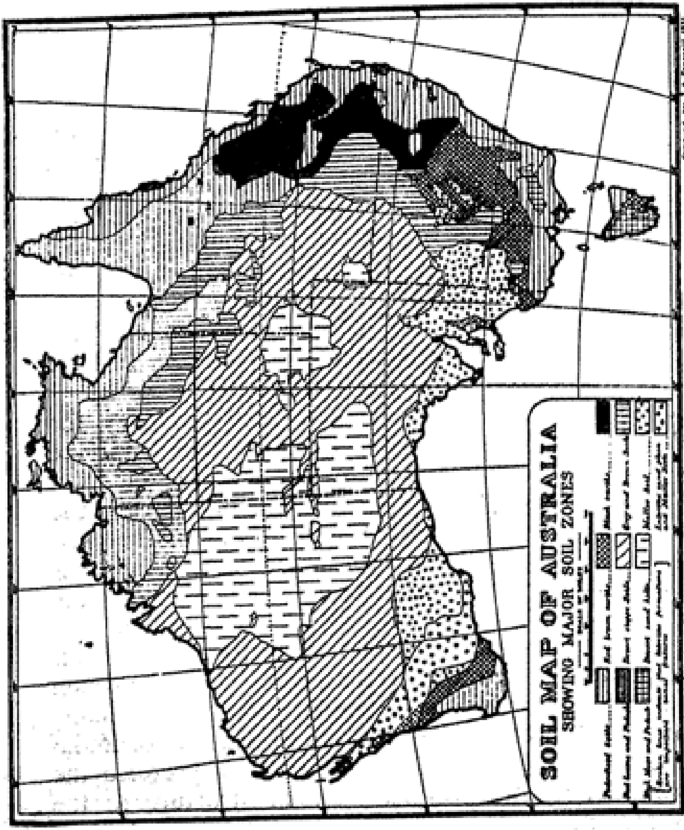


Figure 48. The Soil Pattern of a Continent.
Courtesy of J. A. Prescott.

DECALCIFICATION.

The removal of calcareous material (calcium carbonate) from a soil by leaching may form part of the weathering processes of normal development towards maturity if calcium carbonate is present in the raw material (parent material) from which the soil is developing, or it may arise as the result of changed conditions which give greater efficiency to the leaching process, either by an increase in the rainfall or by a more effective activity of water already available.

THE ORIGIN OF LATERITE AND LATERITIC SOILS.

In the tropics the body of many of the soils is extremely rich in accumulations of oxides of iron and aluminium very similar to the most fully developed accumulations of these substances in certain horizons of some podzols. These tropical soils are called laterites, and it has been supposed that under the climatic conditions obtaining in these hot regions a special kind of soil weathering, which has been termed laterization, is at work. This has been supposed to be responsible for the removal by downward washing into the ground (technically leaching) of the silica present in the original soil so that practically nothing is left but the red cinder-like residues of oxides of iron and aluminium which sometimes extend downwards from the surface of the ground to a depth of forty feet or more.

The work of Prescott in Australia gives us an entirely different and more acceptable explanation of the origin of these soils. They are regarded as products of a series of geological phenomena and soil-forming processes of great antiquity. The first stage is visualized as one of extreme podzolization, including the production of thick horizons of accumulated oxides of iron and aluminium at some depth from the surface. This appears to have taken place

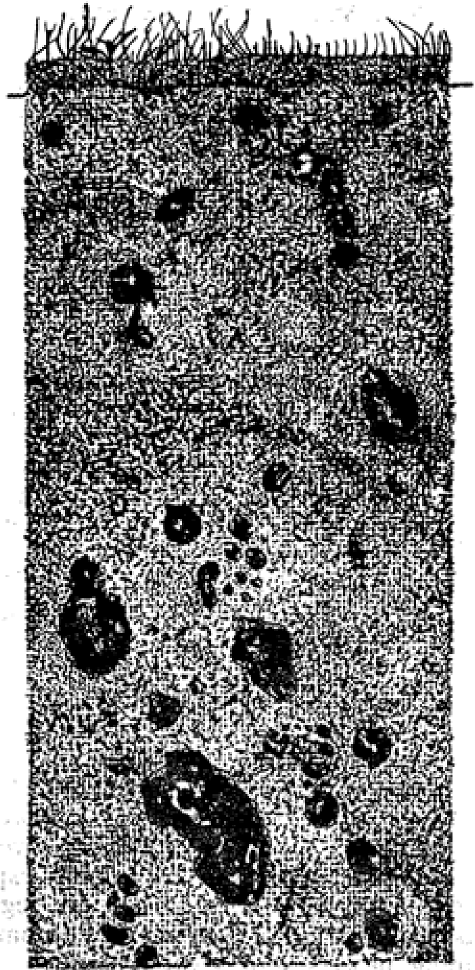


Figure 49. Reddish-Brown Lateritic Soil.

The diagram shews six inches of darker surface soil over the depth of soil rich in sesquioxides. In true laterites it is usual for a cellular iron-rich crust to be developed. This surface-crust may be sufficient to prevent the growth of vegetation. *Drawn by S.G.B.-B.*

in a region reduced by the geological processes of sub-aerial denudation to the condition of a plain only a little elevated above the level of the ocean (peneplain is the technical word for such a plain). Subsequent uplift on a scale which is well known to geologists would explain the present considerable elevation of many of the deposits we are considering. The next stage is visualized as one of erosion by which the upper less resistant portions of the soil were completely removed to leave its indurated lower horizons exposed at the surface.

Soils belonging to the laterite group are laterites and yellow and red lateritic soils. The difference between laterites and lateritic soils is in the proportion of silica left in the soil. It has been suggested by Martin and Doyne that where the silica-alumina ratio in the clay fraction of the soil falls below 2·0 the soil should be called *lateritic*, and when the ratio is below 1·33 the soil should be termed *laterite*.

GLEYING OR GLEIZATION.

Any pervious soil covering the floor of a valley and forming the low-lying land on each side of the stream is subject to flooding and its deeper horizons are permanently wet and water-logged. In such soils there is, indeed, a depth below which any hole we dig will fill up with water. If we can imagine the top of the water-logged layer we shall have a mental picture of a more or less level plate which is called the soil-water-table. Below this water-table the soil is saturated with water, and, when seen in section, the soil here exhibits a *saturation line*. Above the water-table air can penetrate into the soil from above, but below the saturation line there is so much plant debris that any oxygen from the air that gets into it is immediately used up and carbon dioxide is formed. In this way, below the saturation line, airless (anaerobic)

conditions occur, and we may describe the soil as being "oxygen-hungry." Such a soil is what is termed a *reducing medium* (i.e. one that quickly uses up any introduced oxygen). Under these water-logged conditions it would seem that the small quantities of oxides of iron present give up their oxygen and the iron combines with sulphur present

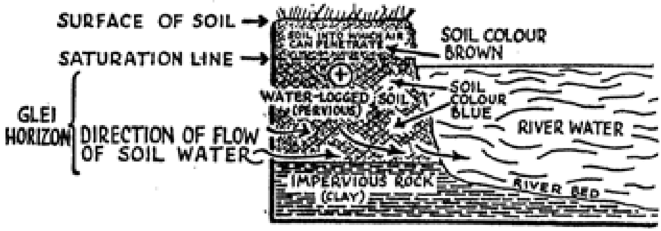


Figure 50. **Glei Soil**

shewing the relationships of air, water, soil and rock. + The layer containing excess of carbon compounds (derived from the decay of plant remains) and therefore without free oxygen: this layer is, from its physical and chemical condition a reduction layer, and from this circumstance blue compounds of iron are formed here. Acting as indices of soil-conditions these blue substances give the glei horizon its typical appearance.

in the decaying vegetation to form compounds, including marcasite, which have bluish or greenish colours when they occur in a state of fine division in the soil. In this way the pervious but water-logged soil below the water-table takes on a characteristic blue or green colour, often with a greyish tint, and is then described as the gley (pronounced to rhyme with "hay") or glei horizon.

Thus we may define glei-soils as water-logged soils, rich in organic matter (*humus*) characterized by greyish-blue or greyish-green coloration which is an index of the reducing medium which constitutes

these soils. Anaerobic conditions prevail in these gleis, and in the organic debris found in them characteristic bacteria are at work. Chemically these soils are rich in carbon compounds while the colour is due to iron compounds of which marcasite (monoclinic sulphide of iron) is stated to be one.

THE ADDITION AND REMOVAL OF SOLUBLE SALTS.

In regions of low rainfall irrigation or flood water tends to bring in soluble salts which afterwards become concentrated by evaporation of part of the water. The process of salt introduction has been called *salinization*. The introduced salts are often chemically changed by reaction with soil constituents. The greatest concentrations produce intrazonal soil called Solonchak. By subsequent leaching or *desalinization* in the presence of calcium such a soil may be diluted into a Chernozem —incidentally by further leaching Chernozem may eventually be converted into a Podzol. If Solonchak be leached in the presence of excess of sodium, sodium hydroxide may be formed and the soil be converted into Solonetz, the process of conversion being termed *alkalization*. By further leaching of Solonetz the soil is converted into a Soloth (plural, Solodi). This dealkalization process is called *solodization*.

CHAPTER XIII

THE SOIL-PATTERN OF THE WORLD

The different climates of the world provide different conditions in different places for the development of the soil-mantle and of its constituent soils. This results in a regional distribution of groups of soils. Regions in which the soils are alike in a broad sense can thus be recognized. Soils in the same group shew similarities of soil-profile. If we make a map of these regions we see the soil-pattern of the world. Russia, a land of wide spaces, is big enough to have an imposing soil-pattern of its own.

WE have seen in the earlier pages of this book that the classification of the individual soils with which each farmer is familiar, from their occurrence on his own farm, is made into *soil-series, soil-types* and *soil-phases*. Not only is this classification a natural one, but it is also actually based in part upon soil properties which the farmer himself may use in describing to his friends the soils in his various fields. From the farmer's point of view—the practical point of view—I would place the emphasis not so much upon the value of the classification itself as upon the advantage of being able to give a *label* to each soil. Being able to do this he is in a position to tell others—with whom he may wish to discuss such topics as land drainage, cultivation,

THE AIM OF THE PEDOLOGIST.

cropping or manuring—which soils he is talking about. It is because such knowledge will help farmers everywhere, as it has already helped them in the United States, that the matter is not merely one of academic interest. It is the aim of modern pedology to systematize soil recognition to such an extent that all the soils known by all farmers—and remember how vast is the sum of this knowledge and of all the related facts about soil-management—shall be identified and so well described that they can be recognized wherever they may happen to occur, by anyone who is sufficiently interested to have made himself familiar with this method of soil study.

METHODS OF REGIONAL SOIL-CLASSIFICATION.

The farmer has a very limited number of kinds of animals and birds to deal with; to the zoologist they are but a few of the many species which make up the two classes Mammalia (i.e. mammals) and Aves (i.e. birds) of the Animal Kingdom. The farmer's cow and his domestic fowl take their proper places in the zoologist's classification in the great groups of Mammalia and Aves; each kind of his farm creatures is a unit in a scientific classification which embraces every species in the Animal Kingdom. The case of the farmer's soil is a close parallel because his few soils, the soils of his own farm, or of his wider life-experience as a farmer, are units in the great soil-groups of the world, or, it may be, in only one of the great soil-groups.

The classification of soils on a basis which is applicable to the whole world has already been indicated in dealing with the *soil-series*, the *soil-type* and the *soil-phase*. Such a classification is most desirable. From a purely scientific point of view it is possible to employ it for comparative purposes,

and there are many practical applications to commend it not only to foresters, planters and agriculturists who happen to be pioneers in new or little developed lands but also to growers of all kinds of crops in countries like England where the practices of agriculture, horticulture and forestry have long histories behind them.

From further consideration we shall see the meaning of the statement that all soil-series, soil-types, and soil-phases fit into the broader classification, that of the great soil-groups of the world.

Just as the horse, cow, sheep and pig are all alike in certain very general features—all for example have a hairy covering and suckle their young—so the English farmer will frequently find that all the soils of his farm are alike in certain very general features. For example, in England, not far below the surface of the ground we very frequently come to a part of the soil which, by the constant downward passage of rainwater, has lost a number of substances which were formerly present (and we shall discuss these more fully later, see page 205). These likenesses among soils are no more sufficient to make all the soils so much alike that they can all be treated exactly alike on a farm or used alike, than do the likenesses between horse, cow, sheep and pig justify a farmer in treating and using all these animals in precisely the same way, but like the hairiness of mammals and the power to produce milk, these soil properties are sufficient to indicate a broad likeness, and sufficient grounds for including them all within the same great soil-group of the world.

The modern way of classifying the soils of the world into great groups owes its origin to the work of the Russian pedologists of the nineteenth century. The value and applicability of the principles they

adopted is now fully recognized by soil-scientists all over the world.

The Union of Soviet Socialist Republics is a wide region, and across it, from the Ukraine eastwards, there stretches a broad fertile belt of many soils which are all alike in being black in colour and possessing properties of exceptional value for the cultivation of wheat. Being a country of wide spaces it is not surprising that a belt of soils so vast and at the same time so strikingly different from the other soils of Russia should early have attracted the attention of scientific workers and should have given rise to much speculation amongst them. Eventually in 1879, there emerged a theory, put forward by Dokuchaev, which served to explain the occurrence of this and other soil belts in Europe. It is a theory which is now universally recognized as part of the explanation of the regional distribution of the great soil-groups of the world. Dokuchaev's classification was a genetic one, based upon the principle that climate is of first importance in determining the general nature of soils.

It is now known, as a result of much detailed study and the accumulation of data in widely separated regions of the earth, that climatic factors, especially the range and seasonal sequence of temperature and rainfall, are of very great importance in soil-forming (pedogenic) processes and are responsible for differences in different geographical soil-belts for differences in the properties of corresponding layers (or more technically and correctly, horizons) of the soils. In passing, it may be added that, in addition to climate, mountain ranges and other features of surface-relief have a modifying influence upon the kind of soil produced, and so also have certain geological materials which either enter into the composition of the soil

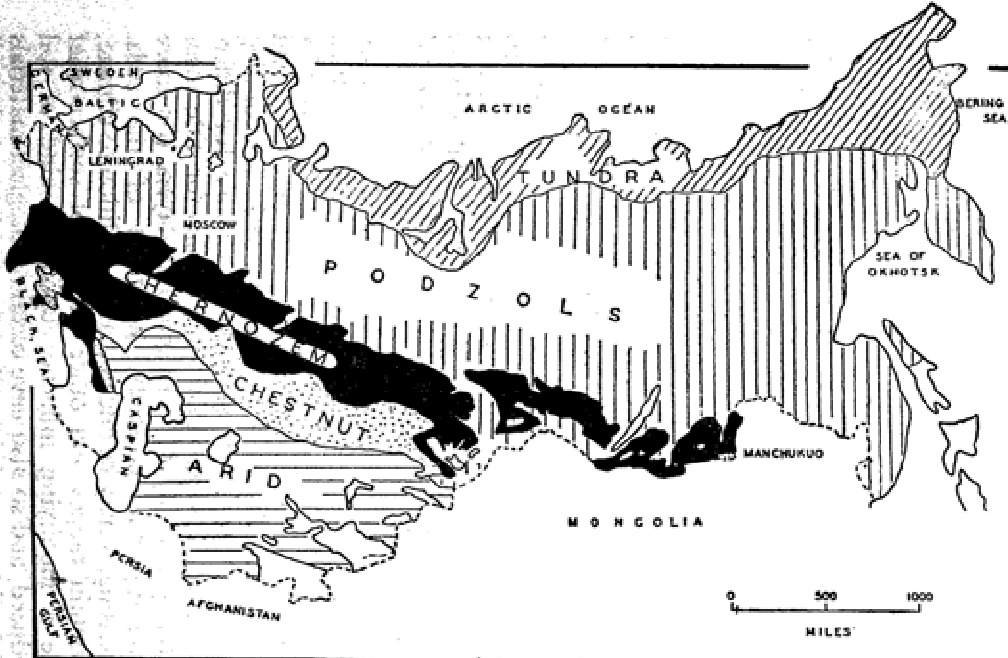


Figure 51. Sketch Map of the Soil Zones of Russia. To shew general arrangement.
Adapted from Glinka by S.G.B.-B. Drawn by Cornelius Davies

or affect the drainage. Again vegetation modifies soils, and lastly, the length of time during which pedogenic processes have been at work leaves a significant mark upon the soil properties, so that some soils may be regarded as mature, others as immature.

To return to the question of climate: to climatic differences are largely to be attributed the great differences that there are between typical soils in the different great soil regions of Russia (see map, Fig. 51).

Let us pass these great soil-zones rapidly in review. The northernmost zone is that of the soils of the Tundra, where the typical conditions include the presence of a permanently frozen horizon a few feet below the surface of the ground; above this is a shallow soil which is usually of a semi-fluid nature, and in many respects not unlike the shallower water-logged soils of low-lying land in England close to the banks of some rivers, being characterized, like them, by the presence of a bluish horizon which owes its colour to the anaerobic conditions prevailing not far below ground. When the top soil freezes in winter the expansion which occurs forces the blue mud up to the surface to be spread over it in little patches or, if there is a tough turf, the turf itself is forced up here and there by the accumulated mud just below it, to form little tufts or hillocks, in which case the mud fails to reach the surface. The native vegetation is very limited and quite characteristic and includes mosses, lichens and shrubs. This northernmost zone occupies the northern part of the Kola peninsula, and in the eastern part of Russia, characterizes the land within the Arctic circle. The zone is continued right across Asiatic Russia, roughly parallel to the northern coast.

South of the Tundra zone is the Podzol zone. Podzols, in the wide sense of the term, are character-

Figure 52. Tundra Soil.

Soil-profile, shewing:—HUM, Greyish-brown organic horizon 3 cm.; below this is a yellowish-grey loose loamy horizon 2–3 cm. thick; BLU, greyish-blue fluid horizon, 8–10 cm. thick; BRY, brownish-yellow loam; COM, compact brownish-grey horizon; at a depth of 40–60 cm. dark spots, apparently organic, are often seen; FRO, ever-frozen horizon 79 cm. from the surface.

Based on Marbut's translation of Glinka. Drawn by S.G.B.-B.

istic of cold temperate and moist cool temperate climates but they also occur in the tropics. In the Podzol zone the main feature of the typical *soil-profile* is a strikingly bleached horizon not far below the surface. This bleaching is due to the removal of compounds of iron by downwardly seeping water that has been rendered acid as a result of the decomposition of vegetable debris on and in the top soil. In the case of typical zonal soils in the Podzol belt, which includes the British Isles, the iron compounds that are removed from upper horizons in the soil are redeposited deeper down in the ground. The removal of substances in solution by water seeping downwards (leaching) is characteristic, and the whole process of Podzol production is called podzolization. Podzolization may be much less intense than in the typical case that has just been described, nor are the iron compounds by any means the only substances that are taken down by the seepage. The Podzol zone is a very broad one, seldom less than 900 miles wide.

South of the Podzol belt, from the Balkans to Manchukuo, Russia is traversed by the Chernozem zone. The Chernozem (Black Soil, as it is often called) is readily recognizable on account of the very dark colour which characterizes its upper horizons. This black or almost black colour is due to the presence of humus which is retained in the top soil because there is not an adequate rainfall, under the conditions of temperature prevailing, to provide the quantity and seasonal distribution of water that would be needed to carry the humus deeper down into the ground. The humus horizon is typically about 28 inches thick and the soil characterized in its lower part by the presence of concretions of calcium carbonate formed by the pedogenic processes. The Chernozem

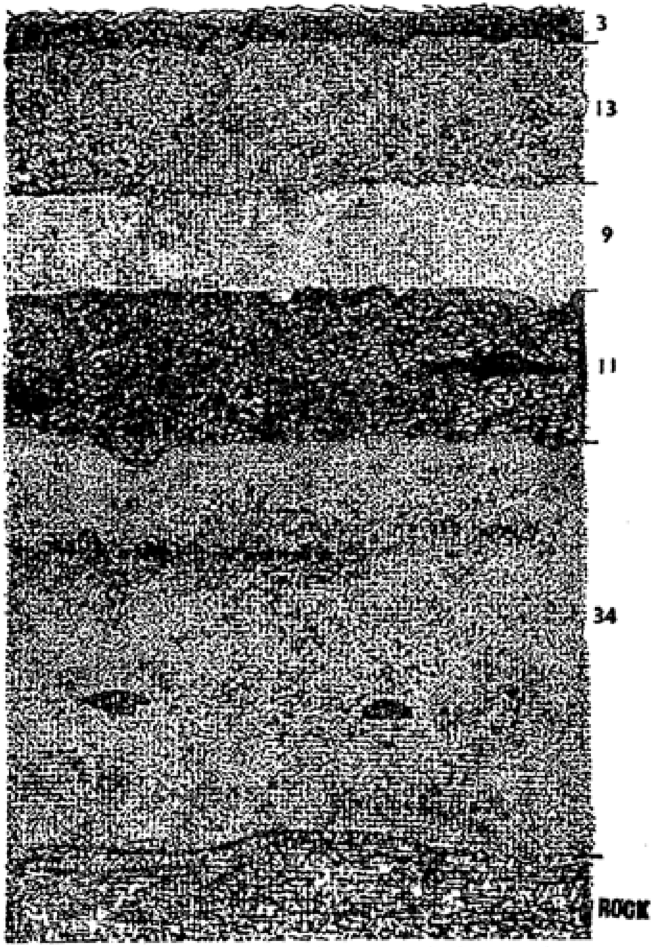


Figure 53. **Soil-profile of a typical Podzol.**

The horizons shewn are (i) 3 inches, A_0, humus-rich; (ii) 13 inches partly bleached A_1 layer; (iii) 9 inches ashy grey soil, the A_2 layer; (iv) 11 inches the beginning of accumulation, B_1, often cemented in places; (v) 34 inches of B_2, soil with some accumulation of sesquioxides, clay and humus overlying (vi) the rock, C. For descriptions and discussion see pages 190-191 and 205. *Drawn by S.G.B.-B.*

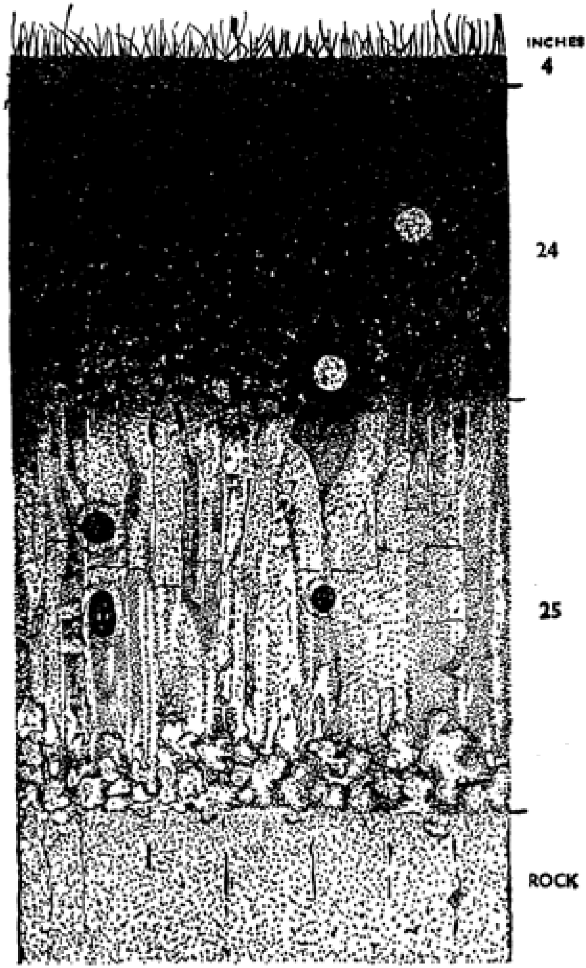


Figure 54. **A Chernozem Profile.**

Twenty-eight inches of black soil (typical of Chernozem) overlie the prismatic calcareous horizon, below which occur lime concretions over the rock (loess). The white patches in the black soil and the black patches in the light-coloured soil are the filled-in burrows of animals, known as *crotovinas*. *Drawn by S.G.B.-B.*

zone is of course the wheat-growing belt of Russia; it is approximately 250 miles wide. In the east this belt is interrupted by mountainous country (see figure 55).

South of the Chernozem zone is to be found the belt of Chestnut Soils extending from the Black Sea to the borders of Mongolia.

The soils of this zone are characterized by the dark brown (chestnut) colour of the upper parts of the soil-profile. Deeper down the soil is lighter in colour and in its lower part the profile has concretions of calcium carbonate like those of the Chernozem soils. The climate is semi-arid, the rainfall of eight to ten inches occurring in the summer. Naturally, there is very little leaching of the soil constituents. The belt in which these soils are found is, on an average, about 200 miles wide.

Between the zone of the Chestnut Soils and the southern boundary separating the Soviet Union from Persia and Afghanistan occur two other major soil belts.

Immediately south of the zone of the Chestnut Soils, in central Asiatic Russia, and well developed around the north of the Caspian Sea is the belt of the Brown Soils also developed under conditions of very low rainfall. In most respects these soils are very like the Chestnut Soils, but they are distinguished from them by their lighter fundamental colour.

Still further south we come to the Serozem or Grey Soils. These are developed under arid conditions. The uppermost horizon of these soils is light grey to light greyish brown. At about seven inches from the surface the soil changes to a browner shade. At about a foot or eighteen inches calcium carbonate, occurring in spots and streaks, again emphasizes the grey colour. Still deeper the soil is typically varie-

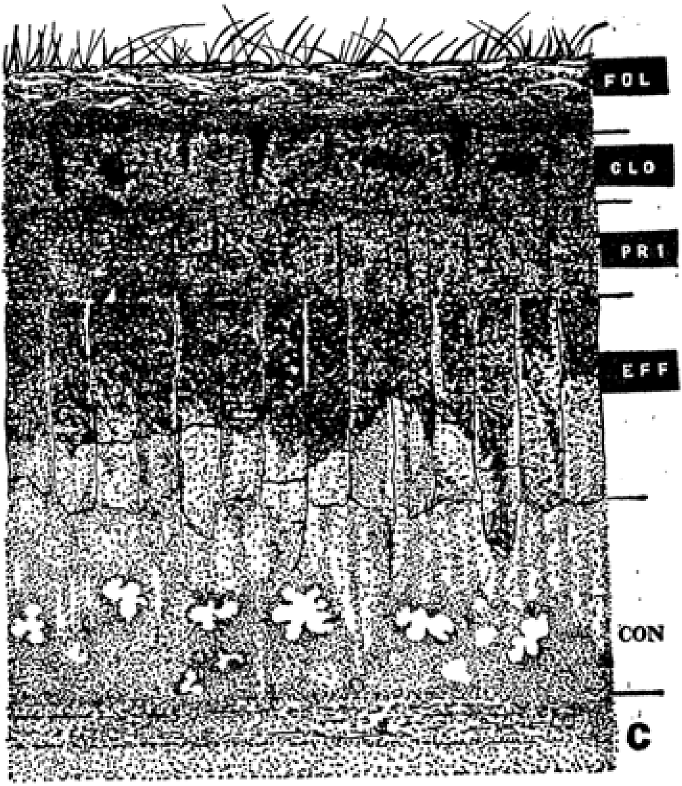


Figure 55. **Chestnut-soil.**

Profile diagram based upon various illustrations and descriptions. FOL, the dark brown foliated surface soil; CLO, a cloddy horizon with tongues of humus; PRI, prismatic layer without lime accumulation; EFF, prismatic layer which effervesces with dilute acid because lime is present, passing downwards into an horizon containing concretions, CON. Below this lies the disintegrating rock, C.

Drawn by S.G.B.-B.

gated by the calcium carbonate and then typically grades downwards into greyish-brown parent material.

These then are the zonal soils of the Soviet Union from north to south.

Tundra.
Podzol.
Chernozem (Black soils).
Chestnut soils.
Brown soils.
Serozem (Grey soils).

Of course some of these zones can be sub-divided, and there are zones of transition, moreover the continuity of the belts may be broken as a result of local changes by such factors as topography, parent-material and vegetation.

Where water conditions are exceptional or where, for some special reason, parent-material, particularly calcium carbonate, has great influence, the zonal soils are interrupted and Intrazonal soils are developed. In materials which have been recently laid down or upon which soil-forming processes have made but little impression the soil is only feebly developed —or not developed at all—and it is classed as Azonal; sometimes the term " skeleton soil " is used for such materials, which include thin stony soils (lithosols), alluvial soils and dry sands.

CHAPTER XIV

A WORLD-WIDE VIEW OF THE SOIL-MANTLE

We must not close our book without a broad view of the soil-mantle, so here it is. This chapter looks at the soils of the whole world. In a geographical survey, zonal, intrazonal, and azonal soils are briefly defined.

WITH increasing knowledge of the natural properties of soils, scientists have been able gradually to build up during the last sixty years or so a natural classification of all the soils (soil-types) of the world into *great groups*. The United States Bureau of Chemistry and Soils has now set out a comprehensive classification of soils on the basis of their characteristics, and in the present writer's account of the soils of the world given in the following pages it will be found that, with slight modification only, the ideas and outline of this American classification have been employed because it is a most useful system when taking a general view of the subject.

WORLD CLASSIFICATION OF SOILS.

In considering the soils of the Soviet Union we have already seen that the great groups there occur in belts. Quite clearly this is the highest category in the world classification, and such soils are appropriately called ZONAL SOILS. But within the zones as a whole and often overlapping the boundaries that would otherwise separate one soil zone from the next, there exist certain natural divergencies

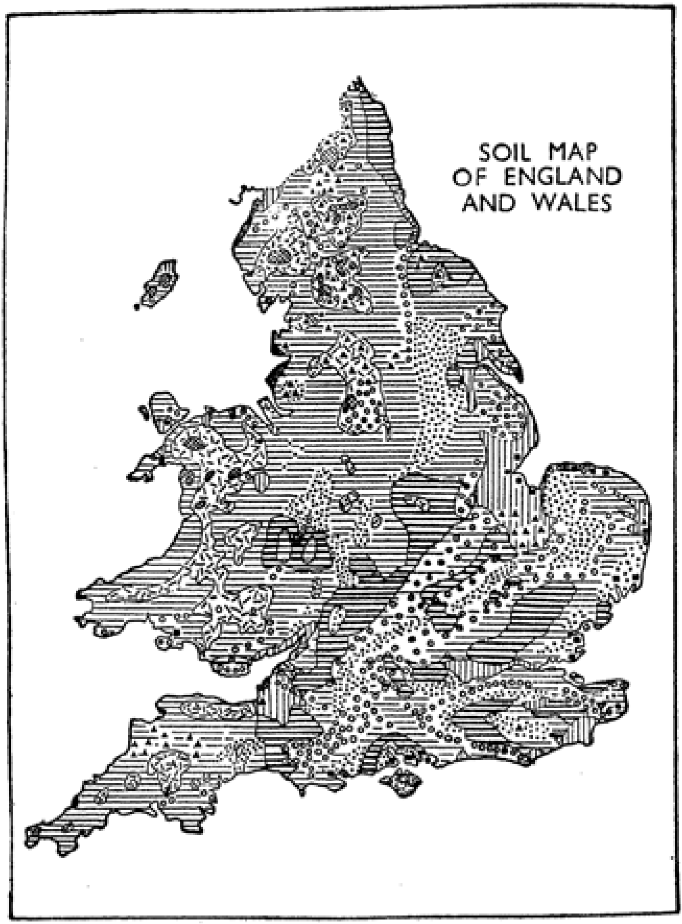


Figure 56.

To illustrate the distribution of the soils shewn in the key on the opposite page: *Compiled by S.G.B.-B.*

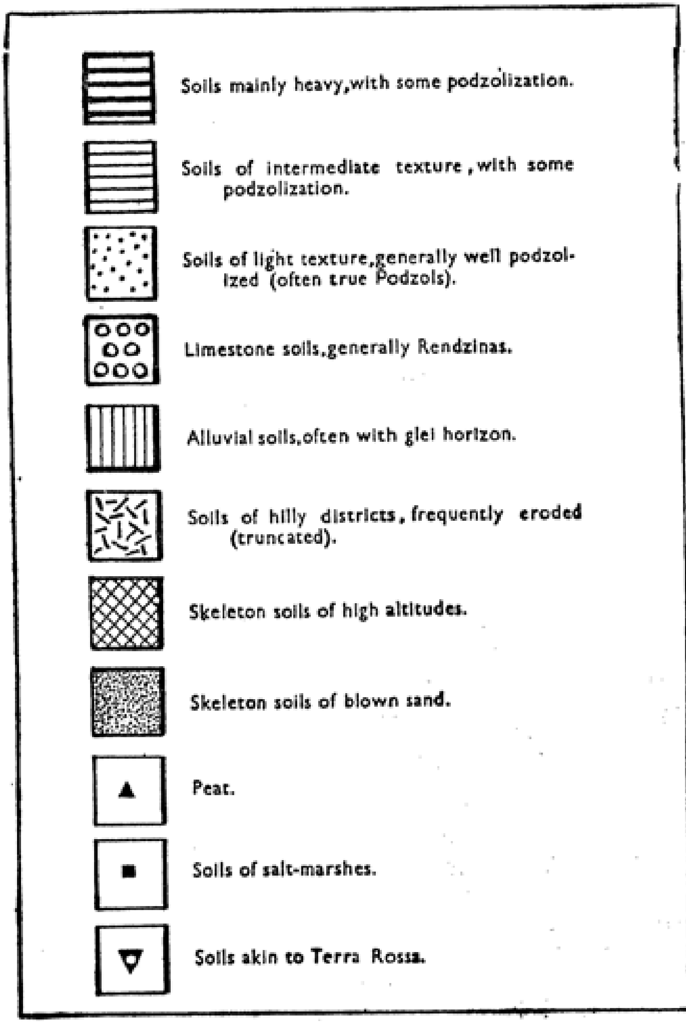


Figure 56a.

Key to the soils of England and Wales, mapped on page 212.

from the normal or expected kind of soil, and this we find is due to the occurrence of certain substances, such as water or various salts, which modify the soil characteristics. Because any of these kinds of soils may occur in two or more of the belts characteristically occupied for the greater part by zonal soils, soils dominated by the occurrence of these substances are termed INTRAZONAL SOILS.

In addition to zonal and intrazonal soils there are certain materials in which the pedogenic processes have not had time and opportunity to produce well-developed soils. These are often described as SKELETON SOILS or AZONAL SOILS. Into this category fall those accumulations of rock debris which are insufficiently weathered to be regarded as true soils.

THE SOILS OF THE WORLD.

ZONAL SOILS	In belts (mainly due to climate).
INTRAZONAL SOILS	Due to special constituents.
SKELETON SOILS or AZONAL SOILS	Undeveloped materials.

ZONAL SOILS.

Zonal soils are, in general, characterized either (1) by development under excessive rainfall which causes leaching or washing-out (from layers near the surface) of compounds of iron and aluminium and their accumulation by re-deposition in the deeper horizons of the soil. Such soils are known as PEDALFERS (from pedon, *soil;* and the chemical symbols Al, *aluminium;* Fe, *iron*). Included in this category are the following soils which we are about to consider; all podzols and podzolic soils and all laterites and lateritic soils. Pedalfers are thus produced by the processes which have been responsible

for the development of soils termed, in the broadest sense, podzols and laterites; or (2) by development under conditions of deficient rainfall, and this results in the deposition in the soil of calcium carbonate. This deposition is brought about by the movement of calcium compounds dissolved in water which is drawn up from below. Soils in which this has occurred are called PEDOCALS (from pedon, *soil*, and cal., abbreviated from *calcium*). The origin of such soils is by the pedogenic process of calcification (see page 191).

It is convenient when dealing with zonal soils to have a system in which we have not to handle more than twenty-five great groups. These major divisions recognized in the classification are set out graphically in the diagram on page 14, from which it will be clear how important climate is in such a systematization. The moisture conditions are indicated in the diagram as humid, sub-humid, wet-dry, semi-arid and arid and those of temperature under general heads of cold, cool temperate, temperate, warm-temperate, hot and tropical. It may be noted that certain parallel sequences of soil groups can be identified, and that they differ from one another as a result of change in either moisture or temperature. This will, perhaps, come out even more clearly if we examine the detailed description of the great groups with which we shall now proceed. For convenience the great groups are serially numbered.

Soils of Very Cold Climates.

Soils formed under conditions of great cold are characteristic of the Tundra belt.

1. *Tundra Soils.*—The soils of the cold north have already been mentioned in dealing with the soil belts

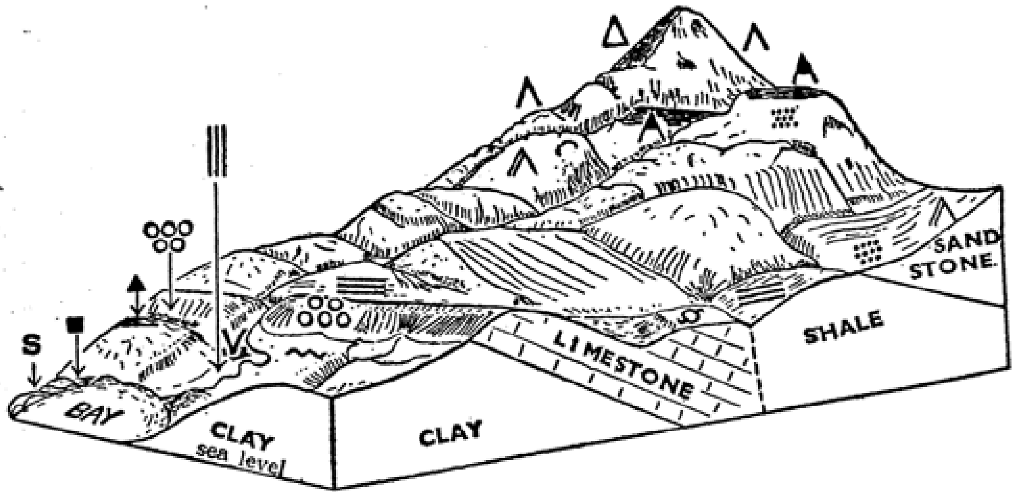


Figure 57

Block-diagram to illustrate some of the Situations of kinds of Soil found in Great Britain.
A key to the diagram is given on the opposite page (below).

Drawn by S.G.B.-B.

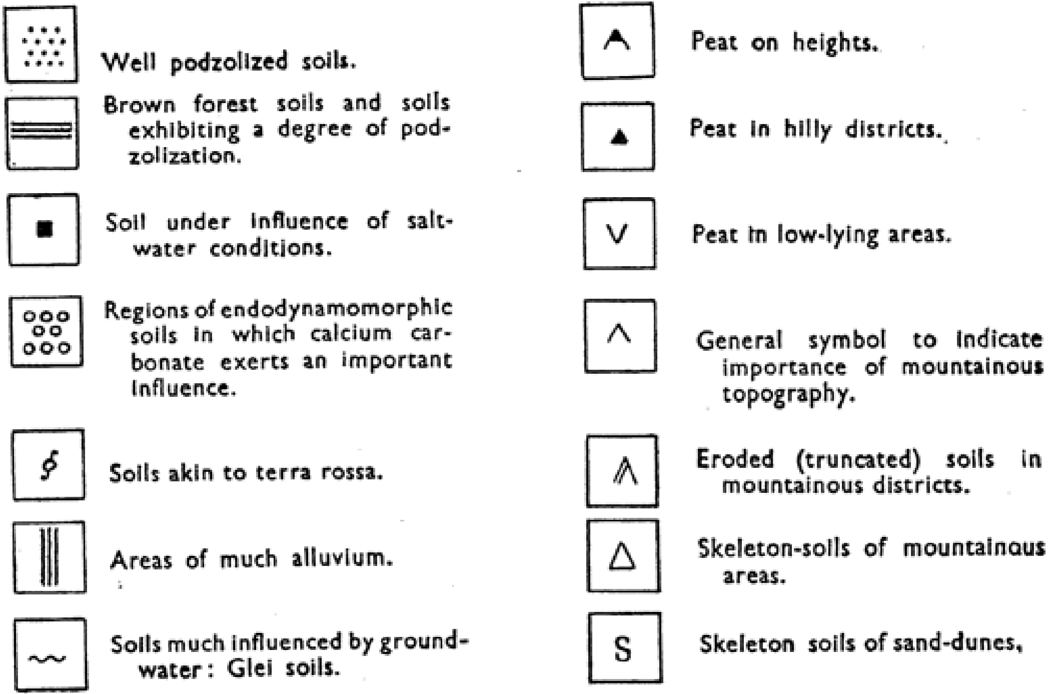


Figure 57a. Situations of kinds of Soil: KEY.

of the Soviet Union, but the following particulars may be interesting and useful here. At ten feet or less below the ground there is a permanently frozen layer of material extending downwards into the earth, sometimes for more than 550 feet. At the surface the soil is brown and rich in humus and frequently swampy. Between this brown soil at the surface and the permanently frozen layer is a muddy, airless horizon, which owing to the absence of oxygen and the presence of organic matter, has a bluish tinge (this is a gleyed soil, see note on gleying, page 195). Blue mud thus lies between the soil and perpetually frozen material below. The extrusion of mud in patches by pressure when the surface soil freezes at the onset of cold weather has already been mentioned (page 203). A somewhat similar phenomenon on a large scale occurs, also in the colder seasons of the year. As the surface soil freezes the underlying water and mud are trapped between frozen material above and below. As the temperature falls still more the freezing is accompanied by an expansion which causes the exertion of sufficient pressure to produce great water blisters forced up from below the frozen soil so that mounds as high as twenty feet may be formed before the water is forced out through surface cracks caused by the uplift.

TUNDRA SOILS.

During the warmer parts of the year, in the lower lying swampy areas of such soils water may run in under gravity below the brown surface soil and exert so great a pressure there as to rupture the soil-crust and allow the mud below to flow out to form patches, or the soil material that is pushed out may be too dense to flow and may remain as little hummocks standing up as much as two feet above the swamp.

Sometimes between the blue mud and the ever-frozen stratum there may intervene a horizon which is

not in a semi-liquid state, and this may have features similar to those of the horizons which lie, in summer, above the level of the river-water in meadow-soils in Great Britain.

SOILS OF HUMID CLIMATES.

Soils produced under humid conditions form a natural series of five great groups.

PODZOL.

2. *Podzol.*—Typical podzol developed under cool temperate conditions, especially in sandy geological formations under coniferous woodland is well known to English students of the soil from its occurrence in certain parts of this country, where it is frequently found in fairly level areas of well-drained sandy tracts, for instance in parts of the Cheshire Plain and under heaths in Surrey and Kent. Similar soils occur, of course, in many parts of the world, as for example, in the coastal regions of Australia normally under sclerophyll eucalyptus forests. In speaking of the soils of Russia mention has already been made of the characteristics of typical podzols.

BROWN PODZOLIC SOIL.

3. *Brown Podzolic Soil.*—Many of the soils of Great Britain fall into this category. This group includes soils which may be described as immature podzols. The podzolization process (see page 191) is in full swing, but it has not yet produced the marked ashy-grey horizon which is so characteristic of the typical podzol. These soils must be distinguished from Brown Forest Soils and the Brown Earths of Ramann (which are described under intrazonal soils, page 239) with which they seem frequently to have been confused.

Figure 58. **Red Podzolic Soil.**

In this diagram lateritic materials are shewn in the process of podzolization. The diagram shews six inches of surface soil over nine inches of podzolized material (POD); below this is an incipient horizon of accumulation (B) with lateritic material below. *Drawn by S.G.B.-B.*

GREYISH-BROWN PODZOLIC SOILS.

4. *Greyish-brown Podzolic Soils.*—Where the podzolization processes have full play in a climate somewhat hotter than that of the British Isles, soils which are in many respects like those of the brown podzolic soils, but with a greyish-brown surface soil, occur. Though less acid than podzols, these soils have a medium to strongly acid upper part.

RED PODZOLIC SOILS.

5. *Red Podzolic Soils.*—The red colour is typical for these are soils of warm temperate to tropical lands and are developed under rather drier conditions than corresponding yellow soils. There must, of course, be sufficient moisture for leaching to be effective in producing the characters mentioned in our previous discussion of the podzolization process (see page 191). This means, of course, that there must be enough rain to keep the downward removal of soil constituents in excess of the upward translocation of soluble substances, especially calcium bicarbonate, see Fig. 58.

YELLOW PODZOLIC SOILS.

6. *Yellow Podzolic Soils.*—Are soils of humid climates in the warm temperate, hot and tropical regions. Conditions which favour the production of the red podzolic soils are supplemented by increased rainfall, and the yellow colour is typical of the different (wetter) circumstances under which the soils are developed.

Unpodzolized Zonal Soils of Cooler Climates.

The soils formed in cooler climates from desert (arid) to prairie (humid) form a recognizable series

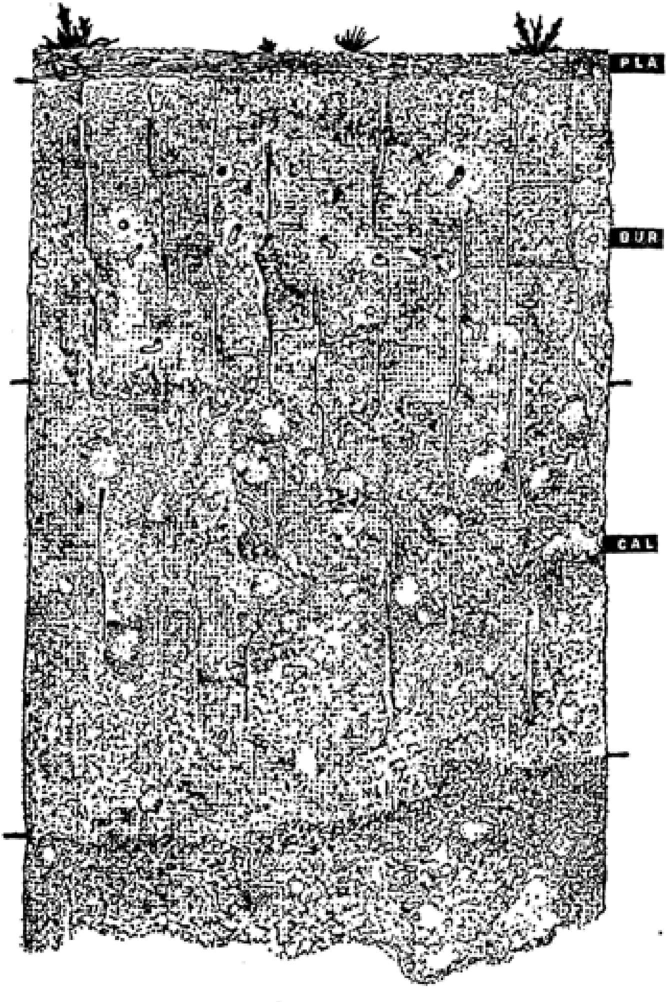


Figure 59. **Desert Soil.**

For description see page opposite

of seven great groups (numbered 7 to 13 in the paragraphs below).

DESERT SOILS.

7. *Desert Soils.*—These, distinguished from the red desert soils of hotter climes, occur in the cool temperate and temperate regions. Near the surface the soil has a low content of organic matter, and the colour is typically light grey or brownish-grey. Below this the soil is lighter in colour and contains calcareous material introduced by the upward movement of ground water—which makes it a pedocal. Normally under scattered shrubby desert vegetation, these soils are capable of producing excellent crops when judicious irrigation is carried out, because they are rich in plant foods which have not been removed by seepage of water, see Fig. 59.

GREY-EARTHS.

8. *Grey-earths* (Brown Desert Soils of some American authors) frequently called Serozem (Sierozem of the official U.S. classification). These soils resemble the Desert Soils, but as they develop under conditions of higher rainfall they have a naturally more generous vegetation. Grey-earths like Desert Soils, being unleached, contain a wealth of plant foods which become available when a proper scheme of irrigation is under-

The profile shews PLA, A_1: about 2 inches of light greyish-brown silt loam, non-calcareous and with a platy structure; BUR, A_2: about 13 inches of silt loam of a rather richer brown colour than A_1, with some columnar structure and penetrated by roots and burrows and tunnels of insects, the cavities are lined with a calcareous deposit in the lower part of the horizon which is itself calcareous; CAL, B: 21 inches compact light yellowish-grey silt loam with high lime content and calcareous nodules, columnar structure feebly developed. Below this is the structureless calcareous rock, a mellow silt loam. This example is based on Lapham, as given by Joffe who points out the Solonetz-like structure of this soil and suggests it is a degraded calcium Solonchak.

Drawn by S.G.B.-B.

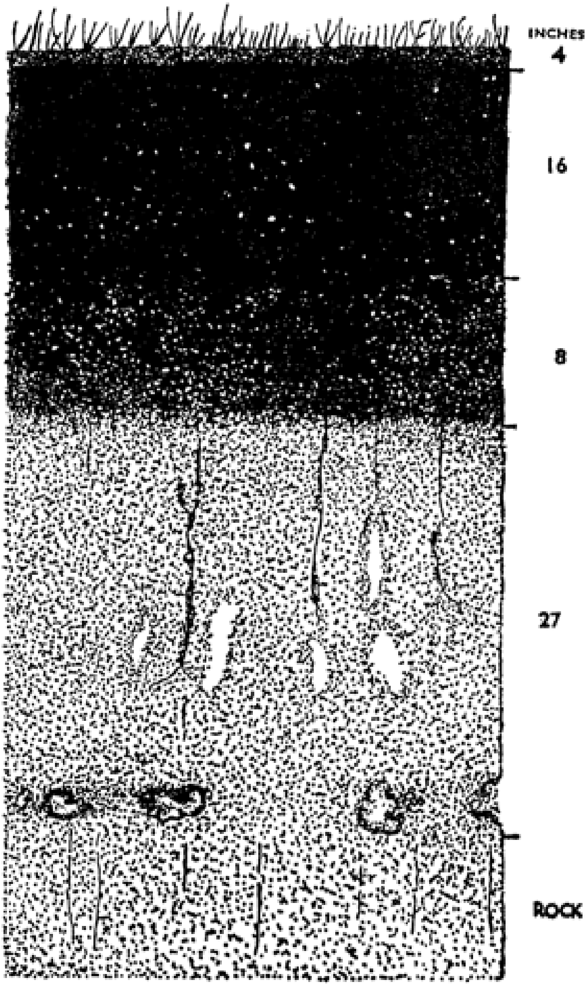


Figure 60. **A Degraded Chernozem Profile.**
For an account of this soil see page 225, and compare this figure with figure 54 *Drawn by S.G.B.-B.*

taken. The soil of the Wimmera of Victoria, Australia, a very fertile wheat area, is, for example, placed by Prescott in this group.

BROWN SOILS.

9. *Brown* (Arid) *Soils* (Brown Pedocals).—The soils of this group occurring as they do under somewhat arid conditions are not likely in spite of their name to be confused with other groups in which the word "brown" occurs. The surface soil is brown and it grades into a white or grey calcareous layer about one to three feet below the surface.

CHESTNUT SOILS.

10. *Chestnut Soils.*—These form a group in some respects like the Black-earth or Chernozem, but they have been developed under conditions of lower rainfall. They are pedocals. The surface horizon has a typical dark chestnut brown colour.

CHERNOZEM.

11. *Chernozem* or Black-earth.—These pedocals are developed in many parts of the world. Their main characteristics are known to us from the now classical researches of the nineteenth century Russian pedologists. With the Russian soils we include similar soils forming a belt, including the Canadian black soils and running down through the United States from North Dakota to Texas. The Regur of India, the black soils of the Sudan, of South-America, and of eastern Australia may also be included, provisionally at any rate, as Black-earths. Chernozem is illustrated in Figure 54, page 207.

12. *Degraded Chernozem.*—In areas of somewhat higher rainfall than that of the typical Black-earth belts, leaching begins to be important and pedocals occur which have some Black-earth characteristics

and yet shew the beginnings of podzolizing processes. They are not yet podzolic, but it is the first link between Chernozem and Podzol, and the chain is continued by the Prairie Soils which come next in our list. See Figure 60 and compare this with Figure 54, page 207.

PRAIRIE SOILS.

13. *Prairie Soils.*—In cool temperate and temperate humid climates, there occur, typically under grass, soils with no lime accumulation in their profile; nevertheless, they are without marked podzolic characteristics. These are the Prairie Soils.

A Soil of Temperate and Warm Temperate Climates.

There is one soil group here somewhat isolated in the classification.

"NON-CALCIC BROWN SOILS."

14. *Non-calcic Brown Soils* (Shantung Brown Soils).—These were first recognized in China. The term "Non-calcic Brown Soils" distinguishes them alike from the Brown Soils of very dry climates, from the Brown Podzolic Soils and from the intrazonal group of Brown Forest Soils. They shew weak podzolization and at the same time there is some calcification of the profile.

Some Soils of Warm Temperate and Hot Regions.

There is a sequence of soil groups in the warmer climes which corresponds in a way to the series Desert to Prairie of cooler latitudes, which has already been briefly reviewed. The soils of these four groups are characterized by a reddish tinge.

RED DESERT SOILS.

15. *Red Desert Soils.*—These are the pedocals of hot deserts. Typically a light reddish-brown horizon at the surface overlies a brownish-red or red heavier horizon which, in turn, overlies calcareous material which may form a deep hard pan.

REDDISH-BROWN SOILS.

16. *Reddish-Brown Soils.*—Soils of the semi-arid warmer climates, these pedocals correspond to the zonal brown soils of cooler regions. The typical reddish-brown surface soil grades downwards into a red or dull red somewhat heavier horizon which, in turn, overlies calcareous material which varies very much in its concentration, so that it may be very soft or thoroughly cemented.

REDDISH CHESTNUT SOILS.

17. *Reddish Chestnut Soils.*—These pedocals of the warm temperate and hot regions correspond to the chestnut soils formed in cooler climates. There is a dark reddish-brown cast on the surface soil which overlies a heavier horizon of reddish-brown or red sandy clay. Below this, at two feet or more from the surface is a calcareous accumulation which, according to the amount of carbonate present is either soft or hardened.

REDDISH PRAIRIE SOILS.

18. *Reddish Prairie Soils.*—Under humid and sub-humid conditions in the warm temperate zone under grass, soils comparable with the Prairie Soils of temperate and cool temperate lands are developed. These are the Reddish Prairie Soils. The dark brown or reddish-brown moderately acid surface horizon grades downwards into a heavier reddish-brown soil which directly overlies the rock.

Tropical Soils.

The tropical zonal soils are included in the official American classification under three heads, as follows:

YELLOWISH-BROWN LATERITIC SOILS.

19. *Yellowish-Brown Lateritic Soils.*—Among lateritic soils these appear to occur under rather moister conditions than the corresponding red soils. Typical of the yellowish-brown lateritic soils is a strongly acid to neutral surface layer of brown friable clay, or clay loam which overlies yellowish-brown heavy, but nevertheless friable, clay.

REDDISH-BROWN LATERITIC SOILS.

20. *Reddish-Brown Lateritic Soils.*—These are the lateritic soils of the drier regions. Texture and structure are uniform throughout. The surface soil is generally darker than the rest of the profile. The soils are neutral to strongly acid in reaction. Typical is a reddish-brown or dark reddish-brown friable or porous granular clay over a deep-red porous and friable granular clay with reticulate mottling in places in the deep parts of the profile (see Fig. 49, page 194).

LATERITE.

21. *Laterite.*—In a typical laterite the brownish-red surface soil overlies a red horizon which is deep and porous. The rock below is deeply weathered, and is red or reticulately mottled. A discussion on the origin of laterite will be found on page 193.

Intrazonal Soils.

The Intrazonal Soils of the world are those in which, owing to the activity of some local condition or set of

conditions, normal zonal pedogenesis is interrupted. The principal cause of this interruption is a set of local pedochemical factors, special chemical conditions in the soil. Typical is the presence of (i) soluble salts or (ii) excess of water (producing marshes or other comparable features), or (iii) exceptional quantities of calcareous substances principally limestone, hard or soft. All these intrazonal soils may occur in two or more of the zonal regions, so that they transgress the boundaries between the soil belts of the world and hence their designation as intrazonal soils.

Soils owing their Principal Characteristics to their Incorporated Soluble Salts.

As has already been indicated, page 197, in speaking of the soil-forming processes that are involved in the production of soils dominated by soluble salts, there are three stages in the sequence of these soils: first, the maximum impregnation with soluble salts or Solonchak stage; second, the loss of salts and formation of sodium hydroxide—this is the Solonetz stage; and lastly, leaching of the Solonetz (solodization) to produce Soloth.

Solonchak.—When conditions of rainfall, see page 197, drainage, and temperature favour the accumulation in the soil of soluble salts, saline soils called Solonochak are produced. The typical profile begins at the surface with a thin salty crust which is naturally greyish in colour; below this, is a fine granular horizon and below this again there is friable salty soil with a greyish tinge. So there is little differentiation between the horizons in such soils and very little structural development. These soils have been termed

SOLONCHAK.

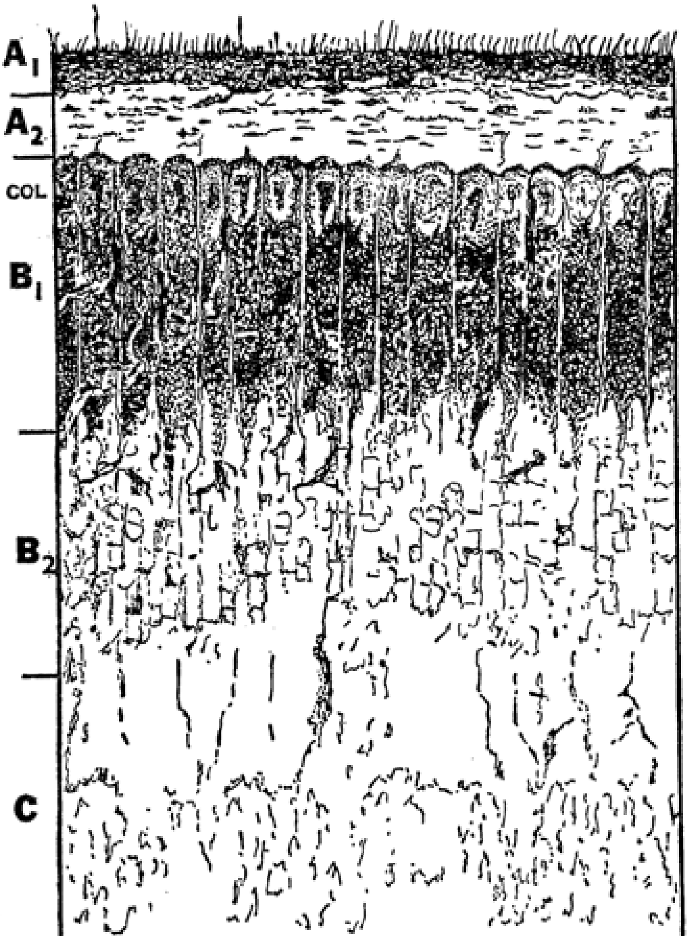


Figure 61. **Solonetz** (see page 231).
Soil-profile shewing chief characteristics: A columnar B_1 layer of dark, hard soil underlies the friable surface (A) horizons. Note the rounded tops of the columns (COL) in the B_1 layer and the laminated structure of the A horizons. The total depth of A and B horizons is 87 cm. (34 inches).

Based on Joffe and Vilensky. Drawn by S.G.B.-B.

"White Alkali Soils," which is a natural name, and from their lack of much structure they are sometimes called "Structureless Saline Soils."

SOLONETZ.

Solonetz.—Under conditions of rather higher rainfall than those obtaining where Solonchak is developed there is a chance that under circumstances otherwise similar a certain proportion of the soluble salts will be leached out and the resulting soil is a Solonetz which has typically a thin friable surface soil, greyish in colour, not more than a few inches thick, overlying a dark-coloured, hard, columnar layer which is usually highly alkaline. The dark colour (which is due to humus widely spread by alkaline solution moving in the soil) gives this group of soils the name of "Black Alkali Soils," while the marked columnar structure, providing another striking contrast with the comparatively structureless Solonchak, accounts for these soils being described as "alkali soils with definite structure." (See Figure 61.)

SOLOTH.

Soloth.—It has already been emphasized that an increased rainfall will gradually remove the soluble salts from a Solonetz with the consequent production of a soil which begins to shew signs of developing towards a Podzol. This is a Soloth (plural Solodi), and the processes which produce it from a Solonetz are called solodization. The Soloth has typically a profile like that of a Solonetz with signs of podzolization imposed upon it: a thin greyish-brown friable surface layer overlying a light coloured bleached horizon which, in turn, overlies a heavier dark brown soil generally with the remains of the columnar structure of Solonetz still visible in it. (See Figure 62.)

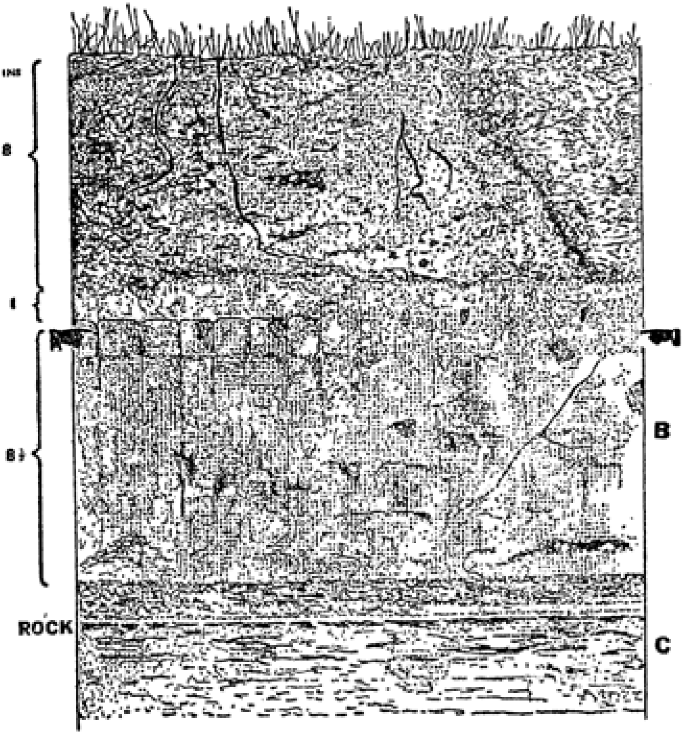


Figure 62. Typical Soloth.

Adapted, with acknowledgments, from plate 36 in Joffe's *Pedology*.
Podzolization processes are removing salts and the columnar structure is being destroyed; note especially the horizon marked with hands: at the left the columnar structure persists, at the right it has disappeared. The ninth inch from the surface is podzolized (A_2 horizon); Rock (C) at 17½ inches. Compare this figure with that of Solonetz (Figure 61, page 230). *Drawn by S.G.B.-B.*

SOILS DEVELOPED UNDER CONDITIONS OF EXCESSIVE MOISTURE.

Next comes a group of soils owing their intrazonal nature and their likenesses to one another to their development under conditions of excessive moisture. The group of these soils which it seems natural first to discuss is that of the

RIVERSIDE-SOILS.

Meadow-soils (or *Riverside-soils*).—They owe their distinctive characters to the influence of ground-water under the fluctuating conditions that accompany (mainly seasonal) differences in the soil-water-table (which is sometimes a perched water-table, sometimes a normal water-table). The surface soil is very wet in the wet periods of the year, in some cases often flooded with consequent overspread of detrital material brought down in suspension by river waters. In the dry parts of the year the surface soil is dry, but the lower horizons shew signs of deficient drainage at no very great distance from the surface. The surface horizon is often dark in colour with accumulation of organic material to a depth of 12 to 24 inches; below that comes a horizon of gleyed soil (see page 195), or at the least a horizon that is greyish, with rusty mottling and spots, the signs of deficient drainage (see Fig. 63).

ALPINE MEADOW SOILS.

Alpine Meadow Soils.—These soils of the mountain regions have developed under excessively moist conditions in a locally cool climate. In summer they bear a luxurious grassy vegetation with flowering herbaceous plants. Alpine Meadow Soils are naturally stony with a shallow top horizon, usually not more than a few inches thick. This top soil is typically dark-coloured owing to a high

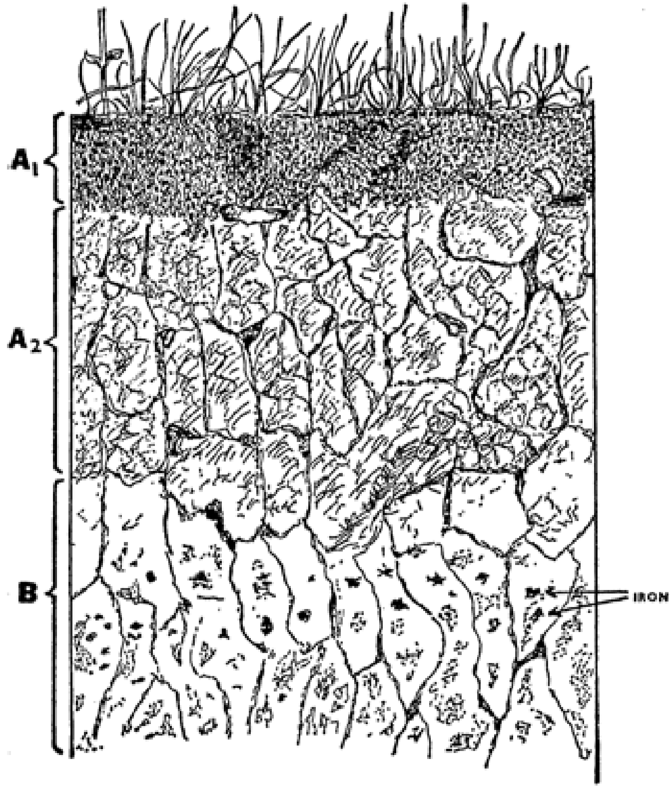


Figure 63. **Meadow Soil.**

Valley of the Great Stour, Godmersham. Five inches of greyish-brown granular soil followed by prismatic brown soil passing at seventeen inches from the surface into a gleyed B horizon exhibiting typical black concretions of iron compounds which indicate impeded drainage.

Drawn by S.G.B.-B.

organic content, and it has a greyish tinge and a crumb or granular structure. Below the shallow surface soil the material sometimes has an orange-coloured streaky appearance; otherwise there is very little profile development.

BOG SOILS.

The *Bog Soils* of the American classification include two kinds of soils, those developed from Fen Peat and Acid Peat respectively. And here it may be mentioned that Cosby and Shaw have said: "Considered in strict accordance with modern pedologic discipline, peat is not soil; it is soil material. Peat is a geological formation—akin to lignite and coal—and as such is entitled to a classification based on its own intrinsic qualities. However, when soil-forming processes act upon peat and related materials, organic soils are produced. These exhibit definite and unmistakable features of profile, with well-differentiated horizons which differ only in detail from those displayed by mineral soils. Hence it is both possible and desirable to classify the organic soils in categories which closely parallel those of the already established system for mineral soils." With this in mind we consider the soils under two heads, both including extremely organic soils:—

FEN PEAT SOIL.

Fen Peat Soil.—This is a soil produced by the accumulation of mild (as distinct from acid) plant debris, generally in humid or sub-humid climates, in localities of marsh or swamp. There is, moreover, little or no admixture of mineral matter (gravel, sand, silt, clay) brought into the decaying vegetation by streams. The deposit is prevented from becoming acid by the alkaline mineral substances dissolved in the marsh water. These substances, of course, originate

from rocks, minerals being dissolved from them by natural drainage water. The complete disintegration of the peat is prevented by the absence of oxygen, which is due to the exclusion of air by the extremely moist conditions.

It may be noted here that increasing accumulation of plant debris may eventually raise the surface of the peat above the level of the alkaline water and, by the decay of the additional vegetable detritus without the neutralizing effects of the solution, acid peat may be formed with entirely different properties, those of Acid Peat Soils.

HALF BOG SOILS.

Half Bog Soils.—When the layer of peaty material is underlain at no great distance from the surface by a grey water-logged mineral accumulation of clay, sand or gravel, the whole soil is termed in the American classification Half Bog.

ACID PEAT SOILS.

Acid Peat Soils.—In regions where the ground is kept almost always wet by rain and mist so that the total precipitation is greatly in excess of total evaporation, plant debris will accumulate, and in the absence of alkaline drainage waters an acid peat will be developed. As in the case of fen peat the accumulation of the organic matter is due to the exclusion of an excess of oxygen by the water present. When acid peat overlies a well-drained pervious non-calcareous rock the mineral material may be expected to shew podzolization; striking examples of this are to be seen on the Cheshire–Derbyshire border where, in quarries in Millstone Grit, the peat above and the rock below are exposed in section. As has been pointed out by A. G. Tansley, the peat may, in such cases, be regarded as an immensely

exaggerated Ao horizon and the whole soil complex as an extreme type of Podzol.

GROUND WATER PODZOLS.

Ground Water Podzols.—These are soils in which horizontal leaching and eluviation take place owing to the fact that water in the lower layers of the soil is constantly draining away. Such soils are called Ground Water Podzols and they tend to exhibit a grey horizon deep in the soil in place of the bluish or greenish grey which is typical of ordinary gleyed soils (see page 195). Economically such soils are interesting and should be distinguished from water-logged soils because the circulating water is sometimes without ill effect upon the roots of plants which are damaged by stagnant waters and the conditions which accompany them. A typical profile of Ground Water Podzol is organic litter over very thin acid humus over a grey leached horizon which may be two to three feet in thickness, over a brown or very dark brown layer which may be cemented to form a pan. Below this are greyish materials (see Fig. 64).

GROUND WATER LATERITE.

Ground Water Laterite.—The natural vegetation under which Ground Water Laterite normally occurs is Tropical Forest with poor drainage of long standing. The climate is hot and humid with wet and dry seasons. The typical profile is a grey or greyish-brown surface horizon over a leached yellowish-grey horizon. At a depth of about a foot or more from the surface begins a reticulately mottled cemented layer (hard pan) which may be several feet thick. There are concretions throughout the profile. The parent material is Laterite.

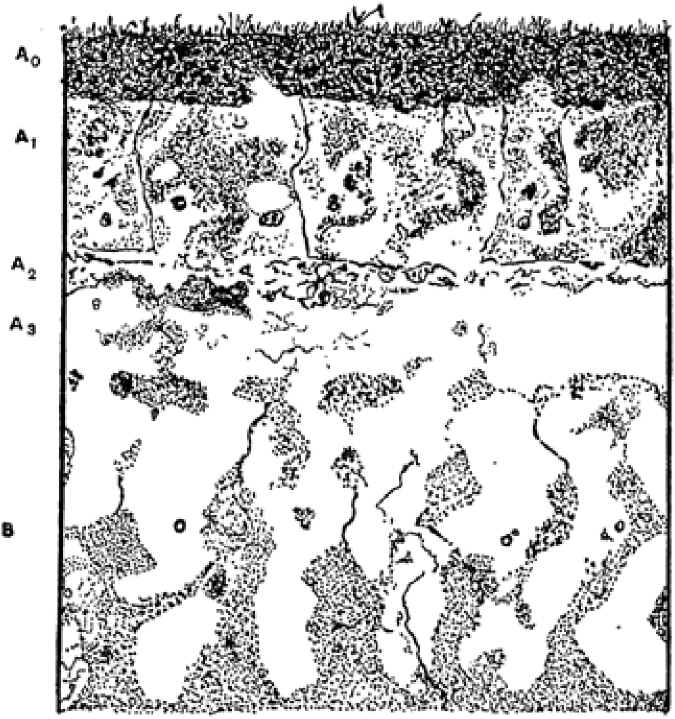


Figure 64. **Ground Water Podzol**
from a monolith collected by Basil S. Furneaux at Cranbrook, Kent.

A_0: 1 inch peaty turf; A_1: 2 inches mottled grey and pale grey, with a few rusty markings; A_2: 1 inch mottled grey and pale grey, broken by roots; A_3: 1 inch mottled grey and pale grey with yellowish brown markings; followed by B, mottled yellowish brown and pale grey.

Drawn by S.G.B.-B.

Planosol.—In the American classification this group embraces all those intrazonal soils with a well-defined layer of clay or cemented material (hard pan) washed down to the deeper part of the profile by soil water which do not fall into the groups of Solonetz, Ground Water Podzol, and Ground Water Laterite. The upper horizons are eluviated, and the horizons of accumulation are more strongly illuviated, cemented or compacted than associated zonal soils. The typical climate is humid or sub-humid, the typical vegetation forest or grass of nearly flat upland (see Fig. 8 and explanation, pages 38 and 39).

PLANOSOL.

Other Intrazonal Soils.

Brown Earths (*Brown Forest Soils* or *Braunerde of Ramann*).—These soils occupy a somewhat transitional position in the classification between typical calomorphic soils (pedocals) and podzolized soils (pedalfers).

The surface soil is generally slightly acid, very dark brown in colour and relatively rich in organic matter. Below this is lighter coloured soil somewhat leached but shewing little or no signs of podzolization since there is practically no removal of compounds of iron and aluminium from upper to lower horizons in the profile. These soils occur under deciduous forest in temperate humid climates and calcium compounds are commonly present throughout the profile because they are brought into the soil by the fall and decay of leaves which have absorbed in growth calcareous materials from the soil-water; this implies parent material (which may or may not be the rock under the soil) relatively rich in bases.

BROWN FOREST SOILS.

Rendzina.—This intrazonal soil is developed from calcareous materials, especially limestones, generally, but not always, soft, and some of the parent material remains in the surface horizon. A typical profile would be five inches of granular friable loam (the colour varies from black through brown and yellowish and reddish-browns to grey) containing fragments of soft limestone lying directly upon the soft limestone rock. In Great Britain these soils are often under grass but are sometimes woodland. Invertebrate animals and small mammals stir such soils up a good deal and play their part in maintaining the calcareous nature of the surface horizon (see Fig. 6, page 26).

RENDZINA.

Terra Rossa.—This term is widely used but ill-defined and often means nothing more than a red soil. It is frequently understood to connote materials which are largely of a residual nature left after the loss by solution of the bulk of a rock which consists almost entirely of carbonates. Such a residuum is naturally mainly of a colloidal nature and reddish in colour. To materials of the kind mentioned, all that is left of such rocks as limestone when seeping water has completed its work, it is not uncommon to find that water-borne detritus has been added.

TERRA ROSSA.

It will be realized that Terra Rossa, in this sense, is perhaps more a material for geological than for pedological study, but of course the nature of the soil is largely determined in such cases by the parent material. The soils developed in Kent in the Angular Chert Drift and in the Clay-with-Flints fit into the classification here.

SKELETON SOILS OR AZONAL SOILS.

These are very young soils which fail to fall into the zonal and intrazonal world-groups because they have not yet developed any of the typical characters of the zonal and intrazonal soils. Azonal soils are classified in the official American classification as:—

1. *Lithosols.*
2. *Alluvial soils.*
3. *Sands (dry).*

LITHOSOLS.

Lithosols are stony materials such as are found in the moraines of recent glaciers, in the gravels of shingle banks and in screes (accumulations of rock debris produced on mountain slopes by weathering, especially by frost-action). See Fig. 65.

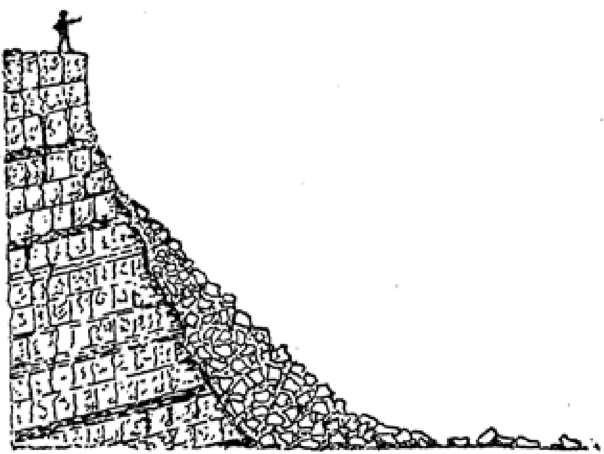


Figure 65. Diagram of a Scree.
The fallen mass of rock debris is produced by the weathering of the limestone which forms the hillside. *Drawn by S.G.B.-B.*

ALLUVIAL SOILS.

Alluvial Soils are the raw materials—sand, silts and clays—often mixed together or inter-stratified and accompanied by gravel and a certain amount of organic material—that are laid down in valleys and plains by river waters. They are frequently under grass and usually exhibit gleization (see page 195).

DRY SANDS.

Dry Sands are quite a usual feature of the land immediately behind the coast line. They are found in many parts of England and Wales, for example, in Lancashire, Carnarvonshire, and Kent, and are quite obviously, undeveloped soils. In the case of these islands they may readily develop with the lapse of time, into Podzols.

In all these cases of azonal soils, profiles will gradually develop according to the zonal and intrazonal factors obtaining in the place of their occurrence and the appropriate climatic, vegetative or pedochemical types of soil will gradually be impressed upon the raw materials.

CHAPTER XV

THE STUDY OF THE SOIL IN THE FIELD

This chapter takes the student out into the open air. It deals with methods of soil examination and soil sampling, gives an account of the soil auger and its use, and concludes with a brief section on soil-surveying and soil-mapping.

EXAMINATION OF THE SOIL-PROFILE.

It has, I hope, been made clear in this book that if we are to know the soil properly we must study it in the field. Some of the ways in which this can be done have already been mentioned, quite incidentally, in earlier pages. The importance of studying the soil, horizon by horizon, to find out what the soil conditions are, what processes are at work, what substances are present and so forth, makes the examination of the *soil-profile* a matter of prime importance.

There are many ways of examining the soil in vertical section. Occasionally, as at the top of a sea cliff or in some landslide, or, again, in a steep-sided river bank, it is thus exposed in nature. But such sites are local and may be dangerous, so that more frequently it is the work of man that provides the opportunity for examination. Quarries and gravel-pits, new road- and rail-cuttings, as well as drainage excavations frequently give us an excellent view of the soil-profile. The farmer digs down through the different horizons whenever he has occasion to make a deep hole, and so he has special opportunities of seeing

what the deeper parts of his soils are like. This is highly important to him from a practical point of view.

The pedologist naturally seizes the opportunities provided by the work of the excavator to examine *soil-profiles*, but there are many instances in which he needs to examine soils where no such facilities are available, and then he must rely upon his own work, and either dig a hole to examine the profile or take other steps to familiarize himself with it.

A special soil-pit is sometimes essential. Its dimensions are dictated by the requirements of the individual case. On the walls of such a pit the soil-profile can be investigated at leisure and soil samples can be taken away in bags, boxes or jars for study later. It may even be an advantage to collect a column of soil in one piece from the surface of the ground down to the rock or to any required depth.

A column of soil such as that just mentioned may be placed in a specially constructed receptacle of wood or metal which, when completed, is really a box, but for the purpose of explaining its construction and use is perhaps better described as a box-like frame. The object of this case is to preserve the soil in a natural and convenient way, for record and exhibition. Such a column is called a *soil-monolith*. The column may conveniently be isolated by marking it out on the face of the pit as a strip of the required width and then cutting away the adjacent soil so that the column stands out like a buttress of masonry against the wall of a building (see figure 66). If it is intended to encase this column in wood, a frame (which is in fact the sides of an elongate box with bottom and lid removed) of the required dimensions is then fitted over the column, a slot at the bottom

SOIL-MONOLITHS.

of the column having first been cut to take the lower end of the frame; when the frame is satisfactorily in place it is converted into a box by adding a board

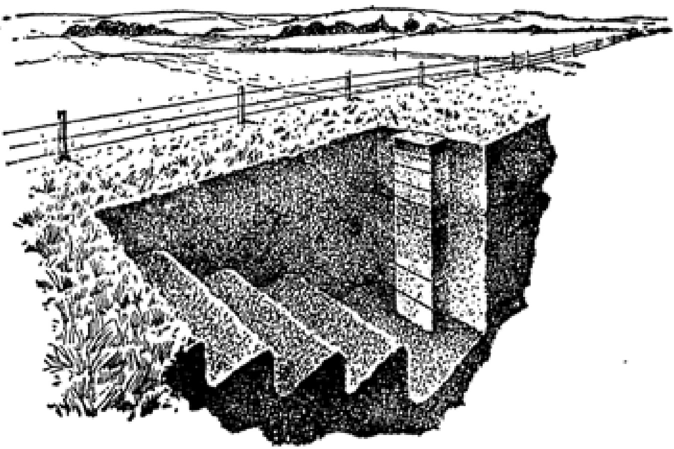


Figure 66.

Sketch shewing a convenient method of preparing an Excavation for Collecting Soil Samples.

On one wall of the pit a soil pillar (shewing a number of horizons) has been left standing; it is suitable for boxing as a soil monolith.

Courtesy of U.S. Department of Agriculture.

which, at its edges, is screwed on to the frame. In order to get the soil more securely in place the board just added may be gently tapped with the handle of a spade or pressed on tight with a motor-car jack (by putting a board on to the opposite wall of the pit, adjusting the jack horizontally and then turning the handle). This enables the operator to fill the box tightly. The column must next be carefully separated from the wall of the pit. This is best done with a spade. With care and by using the right leverage the monolith can be detached so that some soil projects

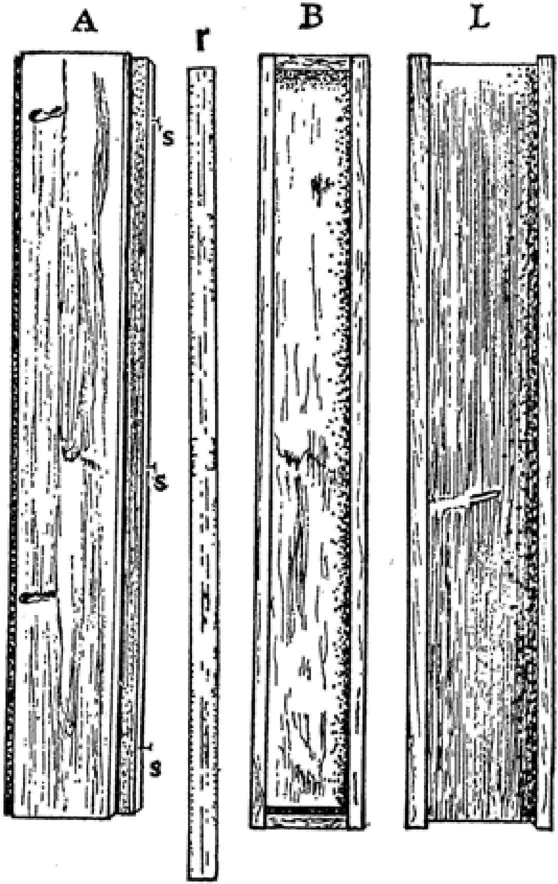


Figure 67. **Monolith Boxes.**

On the left is a soil-box closed (A); the screws (s, s, s) are in position, but not driven home. Next to this is a metre rule (r) and then comes an empty box (B)—the bottom of the box screwed on. L is the detached lid. *After Brade-Birks and Dubey.* *Drawn by S.G.B.-B.*

from the box. If the box is now laid on the ground the soil face can either be trimmed up so that it presents a rough structured face or be cut smooth, as a farmer would cut the soil when digging. In the latter case a carpenter's saw may be used, either the toothed edge or the back being employed. Both the types of face mentioned may be desirable; the rough surface shows the natural soil units while the cut face admirably exhibits mottling and any concretionary features. Care must be taken not to *smear* the surface of the soil, so that particles from one horizon are dragged across the face of another. As a matter of fact both skill and patience are required in preparing monoliths, and every different kind of soil presents its own difficulties. In the case of a very gravelly or sandy soil it may be impossible to cut a monolith, and it may be necessary to build up one that is more or less artificial. Normally, in a carefully prepared specimen, structure and horizonation are clearly exhibited, and the pedologist has a very useful permanent soil-sample, in as natural a state as can be expected.

For the protection of the trimmed surface a lid is required, and this will be described in the following particulars of the container:—

The inside dimensions of the frame which is eventually to form the ends and sides of the elongate box need not be more than three-quarters of an inch to one inch deep and two inches broad, though 1½ inches deep gives greater strength to the monolith, and a breadth of 4 to 6½ inches gives a much better view of the section. However, each increase in these dimensions increases the weight of the monolith and the difficulty of transport. The length of the box is of course determined by the depth of the soil-profile. In dwarf soils the whole profile may be comprised in less than a foot. Forty inches is a length of box

frequently employed, but four feet six inches, or even more, may be needed to shew the profile properly. The frame itself has deal sides $\frac{5}{8}$ inch thick, with ends of elm one inch thick. It is of ordinary construction and calls for no special comment. The board added to convert the frame into a box is of deal, the same length and width as the outside dimensions of the frame. The lid, also of deal, is the same length as the frame, but $1\frac{1}{2}$ inches wider. The ends of this lid are left without any further addition, but along the sides of the lid are screwed fillets of $\frac{3}{4}$ inch square deal, which can be screwed into the sides of the box as required. If the lid be properly made it slides smoothly on to the box without disturbing the surface of the monolith, and, since the screws are inserted sideways into the box, its face is not disfigured by screw holes (see Fig. 67).

Sometimes the soil-monolith is imitated, often on a quarter scale, by glueing soil, horizon by horizon, onto a strip of wood, which may conveniently be $18'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$. American whitewood is very suitable for the purpose. This method, which has been employed by Prescott in Australia, provides a very useful record and occupies very little space.

Figure 68. **The Soil-Auger.**
The portion of the auger used to withdraw soil from the ground. A usual diameter is one inch. *Drawn by S.G.B.-B.*

In the field an essential implement is the soil-auger. This tool is conveniently made by removing the point of an ordinary wood-auger and welding its stem on to a T-piece of mild steel. The T-piece acts as a handle

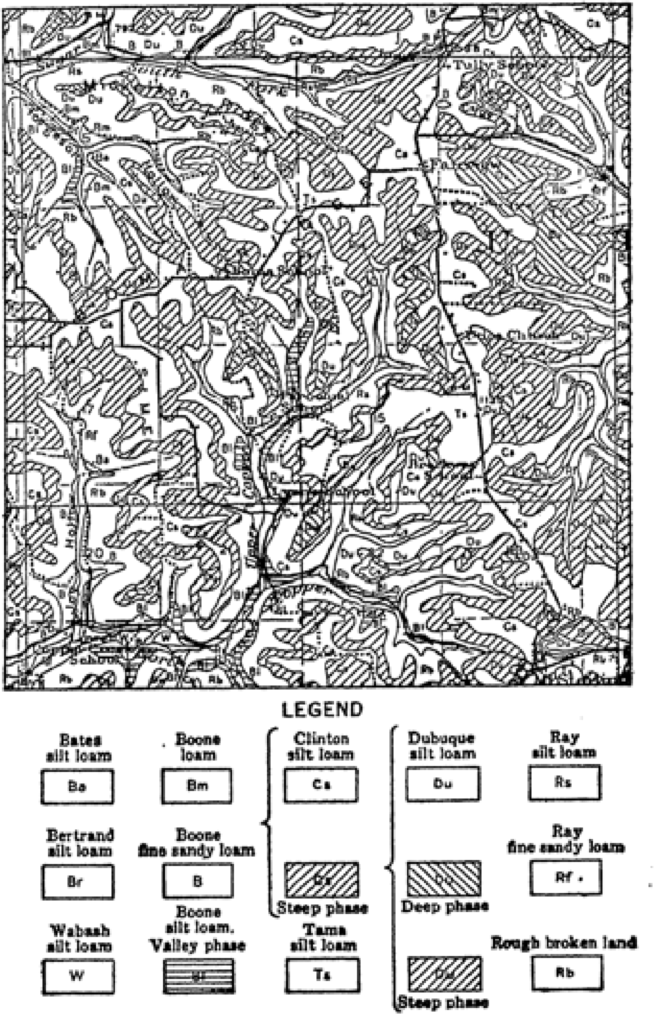


Figure 69. **Reduction of part of a Soil-Map.**

It illustrates the distribution and location of soils. Such maps are usually coloured. The original scale is one mile to an inch; here it is one mile to ½ inch. *Courtesy of U.S. Department of Agriculture.*

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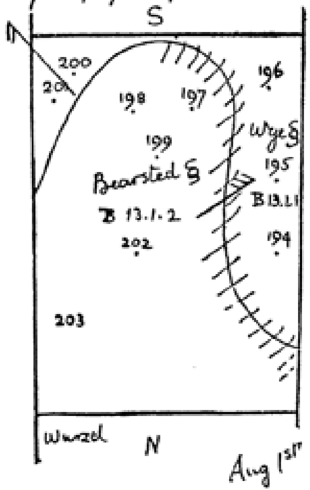
Peas following marrow stem Kale folded & sheep corn fed. Chicken manured previous year. Peas sown last week in April. Dwarf crop, pretty clean



73

Name: Symbol: No.: 194
Location: A. Farmer   Date: August 1st 1933
Prospect Farm, Lees.

1. Geology: Folkestone Sand downwash over
2. Origin: Valley Brickearth
3. Topography: See map.
4. Drainage: Excellent
5. Reaction: Acid
6. Profile: About 30" of grey-brown sandy loam over reddish brown loam

195 10" grey-brown sandy loam over reddish-brown valley brickearth loam to silt loam

196 as 195
197 8" grey brown loamy sand running into brown loamy sand to below 42"
198 6" grey brown loamy sand over pale brown sand
199 as 198
200 Over 42" of dry gravelly brickearth
201 As 200
202 Coarse loamy sand somewhat gravelly to coarse sandy clay loam at 30"
203 As 202

Figure 70. **Two pages from a Field Notebook.** *Courtesy of Basil S. Furneaux.*

THE SOIL-AUGER.

and may be conveniently graduated by marks at 6-inch intervals. For tall or fairly tall people a convenient overall length of auger is 44 inches, for those who are shorter an auger only 38 inches long is better. The village blacksmith, if he does oxy-acetylene welding, is able to make this useful tool for about ten shillings, or, in case of difficulty, it can be ordered from Mr. W. G. Gillingham, The Forge, Wye, Kent, who is experienced in making it.

In using the soil-auger it is screwed six inches or so into the ground and then withdrawn *by pulling*. After the soil trapped, in this way, in the whorls of the auger has been examined and discarded, the cleaned auger is re-inserted into the hole already made, and is then screwed into the next deeper six inches of soil, after which it is again withdrawn *by pulling*. The process is repeated as often as necessary, care being taken by the operator not to insert the auger too far at a time, otherwise there is danger of muscle strain or even rupture.

Soil Surveying and Soil-Mapping.

To the farmer who wishes to take every advantage of modern scientific progress in agriculture, a soil-map of his farm—something quite distinct from a *geological* map—is much to be desired. The map will shew the extent and boundaries of the *soil-series*, *soil-types* and *soil-phases* occurring on his land.

A base map is required. The most convenient in this country is that of the Ordnance Survey on a scale of six inches to one statute mile.

THE SOILS OF THE FARM.

If nothing is known of the soils of the farm some convenient spot is chosen from which to begin the mapping and the soil is there

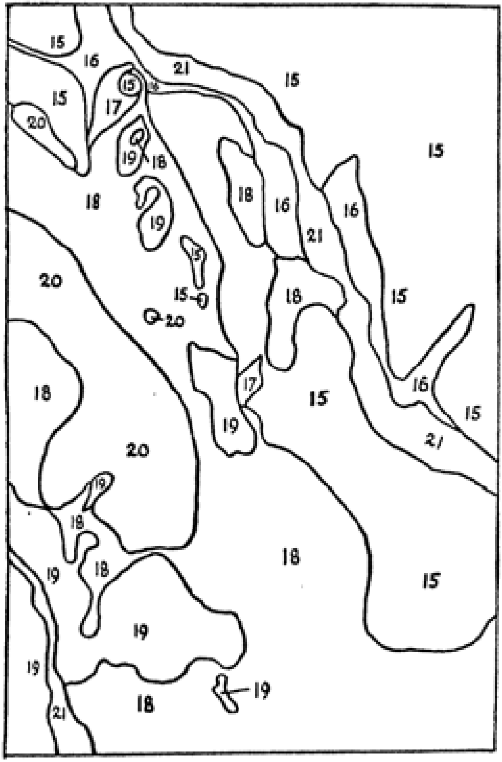


Figure 71.

Soil Map of Part of Monmouthshire. Scale, Three Inches to One Mile. Reduced from a six-inch map made by Messrs. D. O. Hughes and E. Crompton. Soil boundaries alone shewn here. Normally such a map is prepared by using the six-inch Ordnance Survey map as a base-map.

For key see opposite page.

examined with the soil-auger. If this examination reveals the existence of a known soil-series, the texture of the surface soil is determined, and the particulars are entered in a notebook and indicated by symbols on the base-map. A traverse (a survey line) is then made in a pre-determined direction across the land and auger samples are examined at suitable intervals and noted.

In this way the boundary between adjacent soils will be determined and indicated on the map. When sufficient traverses have been made it will be possible to complete the soil boundaries on the map.

Under some circumstances it will be advisable to have soil-pits excavated so that a thorough examination of the soil can be made by the methods already explained (see page 244).

No amount of written instruction can take the place of practical experience and the best way to learn to make a soil-map is to get into touch with an experienced soil-surveyor.

In many parts of the British Empire and of the United States detailed soil-maps have been prepared

Key to the Soil-Series.

15. *Llandinam*. Derived in situ from Grey Mudstone and Shale (Silurian). Drainage, good.
16. *Llandinam Colluvial*. Derived from Grey Mudstone (Silurian). Deep soils on steep slopes. Drainage, free.
17. *Cegin*. Derived from Grey Mudstone and Shale (Silurian). Drainage, impeded.
18. *Rumney*. Derived rom Red Marls (Old Red Sandstone). Drainage, good.
19. *Perthellick*. Derived from Red Marl and Fine Grained Sandstone (Old Red Sandstone). Drainage, impeded.
20. *Monmouth*. Derived from Red Sandstone (Old Red Sandstone). Drainage, free.
21. *Alluvium*. Unclassified. Derived from Grey Mudstones (Silurian) Red Marls and Sandstones.

Courtesy of Prof. G. W. Robinson.

and published. A start has been made in Great Britain and a good deal of mapping has been done in certain places, but no wide series of detailed maps is yet available. It is hoped that this will be remedied before long. In the meantime information about soil-survey matters in this country can be obtained from the Director, Soil-Survey of England and Wales, University College of North Wales, Memorial Buildings, Bangor.

CHAPTER XVI

SOME PHYSICAL FEATURES OF THE SOIL

This chapter is mainly about soil-structure, that physical property of the soil which accounts for clods and cracks and columns and clefts and crumbs; but a place is found for mention of soil-compaction—with a brief account of the Davies Soil Compactometer—and of soil consistency or constitution.

SOIL-PHYSICS.

SOME topics already considered in detail in the present book come within the purview of the soil-physicist; for example, *alternate wetting and drying of soils* (considered under weathering) and the *mechanical composition of soils*, are his concern. But there are other considerations falling into the same category, which are of interest to the practical farmer but cannot be given much attention here. One such subject is soil-capillarity. To those who are specially interested in the way in which pore-space in rocks and soils affects the supply of water to the roots of plants a textbook of soil-physics will give much information.

SOIL-COMPACTION.

The question of soil-compaction, again a most important one from a practical point of view, is a very different story. We know, of course, that soil-compaction is of great importance in influencing the growth of such agricultural plants as cereals but practically nothing is known about the optimum conditions for plant growth. Sometimes, by chance,

the growth of a cereal is exceptionally good along the wheel tracks of a heavy farm implement which happens to have been driven across a part of the crop when the seed was newly sown, but when it is sought to reproduce the conditions experimentally the investigator may meet with little success because soil-moisture, and consequently soil-consistence, are among the variable factors which have a bearing upon the result.

Experiments on soil-compaction have been facilitated by the invention of the Davies Soil Compactometer (See Figure 72). This instrument consists essentially of

Figure 72.

A simple form of the Davies Soil Compactometer.

The illustration shews the pointed probe, the scale of the spring-balance and the handle of the instrument.

Courtesy of Cornelius Davies.

a probe attached to a spring balance which is actuated when the probe is thrust into the ground. The compactometer has been equipped with a self-recording attachment which draws a depth-consolidation curve to exhibit the varying compaction at different soil depths (see Figure 73).

Of course it is not only those properties of the soil which are used in identification and classification that are of interest to the farmer. He is also especially concerned with such chemical properties of the soil as the presence or absence of the needful quantities of the common plant foods and those other substances which, though only required in small quantities, are nevertheless very important for the health and success of the plant. As far as plant foods are con-

cerned, these come mainly into the province of the chemist, and they can generally be supplied artificially to the soil as soon as the farmer has consulted the agricultural advisory chemist and has learnt from him what the particular needs of his land are.

There are, in addition, properties of the soil which are of use in making accurate descriptions of individual soils, so it is well worth while to pay attention to them.

Soil-Structure.

STRUCTURES.

We have already seen that a mechanical analysis of the soil or an examination of it by the method of handling enables us to determine what is known as *soil-texture*, in other words to determine either accurately, in the laboratory, or within defined limits, in the field, the proportions of the soil that consist of sand, silt and clay. Soil-structure is an entirely different property and is best understood by looking at the soil itself. If the soil in your own garden has been fairly recently turned with the spade, unless it is very sandy, you are not likely, when you look at it, to see all its individual grains as separate entities. Much more likely you will see them stuck together in smaller or larger groups to form crumbs of soil or little lumps or clods, and if you have an opportunity to examine the soil profile of a fairly heavy soil on the wall of a pit or some other excavation, especially if the excavation has been open long enough for some of the moisture to have dried out of the soil, you are likely to see cracks extending deep down into the ground and so breaking the soil up into prisms. Near the surface, where roots are numerous, you will probably see something rather like the features

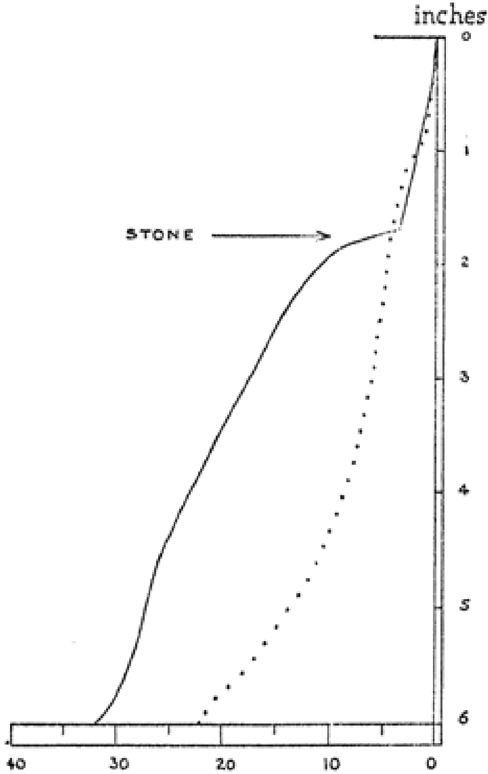


Figure 73.

Curves obtained with the Davies Soil Compactometer.

The dotted line was obtained when there was no obstruction in the path of the probe. The unbroken line indicates the effect of a stone obstructing the probe. *Courtesy of Cornelius Davies.*

already noticed on the surface of garden soil, small crumbs and granules into which soil so often breaks up near the surface of the ground. These things we have mentioned, crumbs of soil, lumps, granules, clods and prisms are *structures*, and when we speak of soil-structure we mean the occurrence, and association with one another, of just such units as these; but perhaps a consideration of structure in clay will serve to give clarity to our notions of *soil-structure*.

CLAY.

Clay has its greatest natural bulk when it is moist, as it generally is when it occurs as a rock (in the geological sense) in deep layers which begin, underneath the soil proper, some little distance below the surface of the ground. When clay dries, however little or however much, it must shrink and shrinkage can take place in three ways: (1) So as to form a series of vertical cracks. This will produce a structure consisting of prisms of clay with the vertical dimension great, and both horizontal dimensions small, rather like a series of bricks standing on end. (2) Or, it may shrink to form a series of horizontal clefts to produce, with a short vertical dimension and two long lateral dimensions, a structure like a pile of roofing tiles. (3) Or, lastly, it may shrink equally in each of the three directions: one vertical, two lateral or horizontal, to produce structures cubical or sub-spherical whose height and widths are all approximately equal. The natural division of the many different soil structures found in the field-study of our subject, into three groups corresponding to those just mentioned is recognized to-day as the basis for the scientific classification of soil-structure. This method owes its origin to the Russian pedologist Zakharov and details have been set out on his framework by a number of workers.

By alternate drying and wetting, the structure

Figure 74. Sharbrooks Silty Clay Loam.

Soil-profile illustrating structural horizons in a heavy soil undergoing podzolization. The top three inches of the soil exhibit granular and coarsely granular structural units; below that, five inches of a cloddy structure occur. The deeper parts of the soil shew prisms, the uppermost being clod-like. *Drawn by S.G.B.-B.*

naturally becomes thoroughly established, and so, in the soil itself, which contains clay, we generally find a special type of structure associated with each group of soils and depending, of course, upon similarities within that group, of such characteristics as chemical properties and clay-content.

So, by looking at the soil, we have established the fact that cracks and clefts on the one hand and coherence into crumbs and grains and larger units on the other hand, give rise to *soil-structure* which is something quite different from *soil-texture* (which the farmer experiences as ease or difficulty in working). The aggregates we have mentioned fit into the framework of Zakharov's classification of soil-structure into three groups which we may call (1) prismatic or columnar; (2) platy; (3) cubical or spherical. We are now in a position to go into somewhat greater detail and shew in a brief systematic treatment of the subject how the different structures farmers may see in their soils fit into the threefold classification that we owe to the Russian pedologist (see Fig. 75).

1. *Prism*-like structures.

In this division the vertical axis is longest and the units are either prismatic or columnar. If the units have sharply defined edges and faces, those without rounded tops are called prisms, those with rounded tops are termed columns. When the edges and faces are not sharply defined, the units are said to be column-like. The sizes of the columns or prisms should be mentioned in any description.

PRISM.

2. *Plate*-like structures.

Sub-divisions of this group may be made according to the nature of the plates and the size of the units.

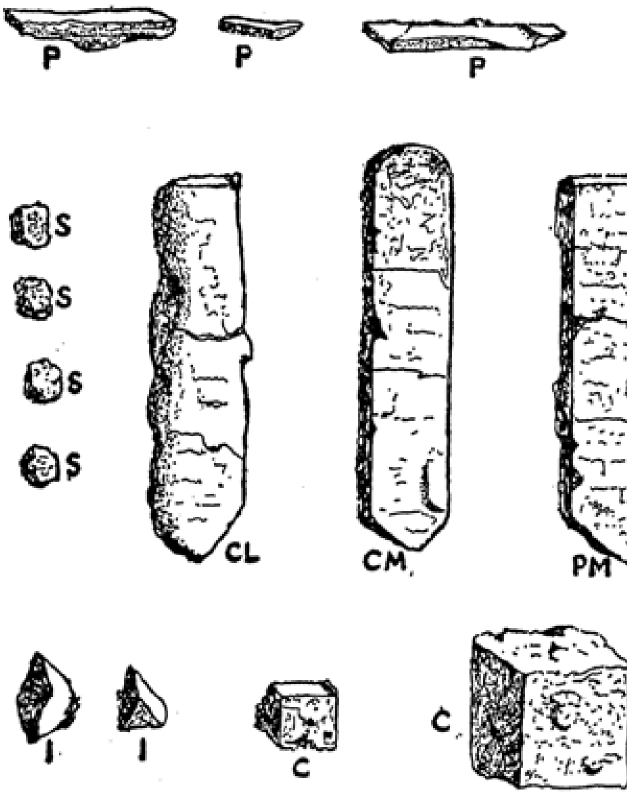


Figure 75. **Soil Structure.**

P, *platy*; S, S, *spherical forms, cuboid to crumb*; CL, *column like*; CM, *column*; PM, *prism*; I, I, *fragmental*; C, C, *cuboid*.

Drawn by S.G.B.-B.

Terms employed for structures in this group include, for flat plates, schistose, more than 5 cm. thick, platy 5–3 cm. thick, laminar 3–1 cm. thick, and foliated, less than 1 cm. thick. Where the units are curved they may be called scales and termed squamose. Phylliform structure consists of thin leaflike layers less distinct and thinner than platy, and if this structure in a soil is geological in origin (as in shales occurring in a C horizon) it is termed laminated. Plates more than half-an-inch thick (say, 13 mm.) are termed slabby by Clarke, and scales are termed by him scaly (more than $\frac{1}{8}$ inch thick, say 3·5 mm.) or flaky (less than $\frac{1}{8}$ inch thick).

PLATE.

3. *Cube*-like structures.

These include indefinite forms, without faces and edges fully developed, called blocks, clods and crumbs, and forms with faces and edges more definite: cuboid, fragmental, nutty, and granular.

CUBE.

If there is a lack of structure and the material consists of large masses of cohesive soil, it is said to be massive. When on the other hand, the soil is structureless because every grain is distinct, as are the individual particles in a sand-dune the material is termed single-grain.

The terminology of soil structure is unsatisfactory because the terms are sometimes not too well chosen and some of them are used in somewhat different senses by different people. The student is therefore best advised to make himself well acquainted with the forms that occur without bothering too much about the names employed, especially for structures in the cube-like group. It is

TERMINOLOGY IMPERFECT.

important to mention the sizes of the units and a sketch of the forms is an advantage.

Soil Consistency.

CONSTITUTION.

Soil consistency or constitution is a property of which much more may be heard in the future. It is difficult to define but is easily recognized by those who handle soils much. A number of terms which have reference to constitution are in common use. *Friable* and *mellow* are two which spring at once to mind. Other designations are *unkind*, *unkindly*, *harsh*, *raw*, *compact*, *consolidated*, *loose*, *floury*, *dusty*, *hard*, *soft*, *sticky*, *plastic*, *powdery*, *pasty*, *puggy*, *indurated*. All the terms used indicate impressions conveyed to sight and touch, or in the use of implements, as when a soil is said to have a *good tilth*, and they are determined by a combination of at least texture, structure, and porosity. Constitution or consistency mainly has reference to soil on the surface which has been sufficiently loosened, generally by cultural operations, to be handled. It is not a permanent feature of the soil. It is something which can often be improved by the farmer, and skill in producing a good consistency is an important part of efficient cultivation.

CHAPTER XVII

A WORD ABOUT SOIL-MINERALS

The mineral part of the soil is derived from rocks. In the change from rock to soil much decomposition occurs, but refractory minerals survive the disintegration of the parent rock as detrital grains. The detection of these in the soil may serve to indicate the source of its mineral constituents. In the processes of soil-formation some new minerals are produced; sericite is an example. In these pages a few typical soil minerals are briefly reviewed.

SOME aspects of soil-mineralogy are closely linked with the study of the origin of the soil. Some mineral of the parent rock may find its way unaltered into the mature soil. Such is especially the case with refractory minerals such as quartz—by refractory minerals is meant those that resist weathering—but this transference of minerals, intact, from parent material to the resulting soil, is by no means limited to the commoner minerals. Some rare mineral present in a soil may indicate to the experienced worker the origin of that soil from a rock which contains the mineral.

SOIL-MINERALOGY.

The close relationship which exists between soil minerals and those of the rock from which the soil originates is illustrated by some Aberdeenshire soils in which relatively unweathered minerals of the granitic parent material appear. There are similar cases

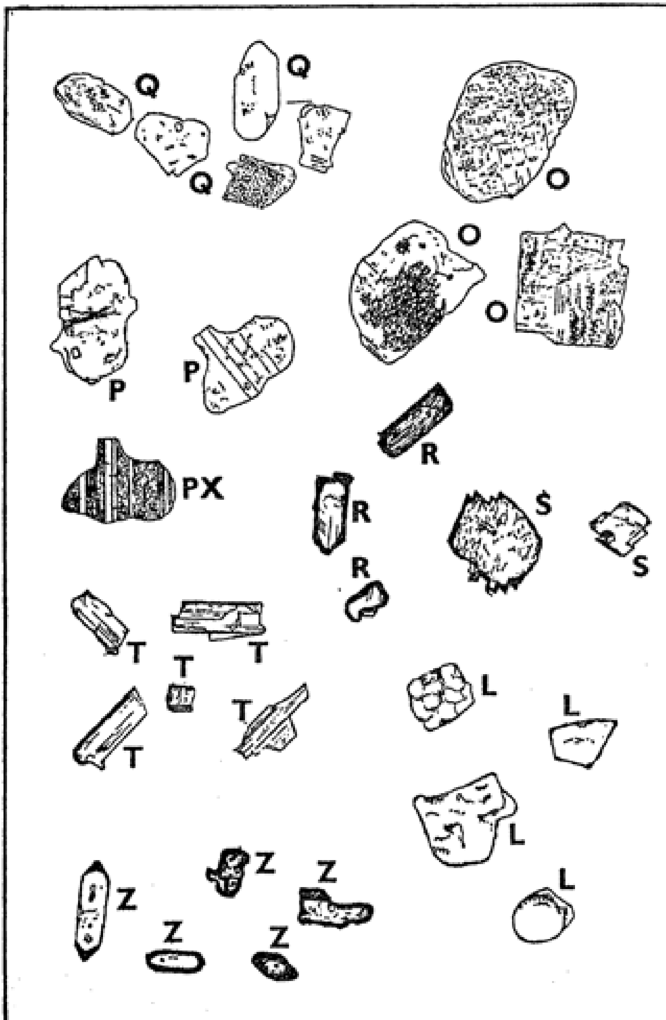


Figure 76.

Mineral Grains seen under the Microscope.

For description see opposite page.

in Kent where glauconite, which is characteristic of some sedimentary rocks in this area, appears in the soils.

There are, however, some minerals—examples are limonite and sericite (secondary muscovite)—which may be formed from other mineral substances while the soil itself is developing.

Sometimes a mineral recognized in the soil is rich in plant foods, but it does not follow that this nourishment is present in a form available to the plant.

Examples of soil minerals are the following:—Quartz, Orthoclase Felspar, the Plagioclase Felspars, Biotite Mica, Muscovite Mica (including Sericite), Tourmaline, Rutile, Zircon, Glauconite, Staurolite, Magnetite, Hematite, Limonite. Particulars of these minerals will be found in general works on Mineralogy, while descriptions of detrital grains, such as occur in soils, may be sought in a work on Sedimentary Petrography. The brief notes which follow are not intended to teach the student of soil-mineralogy all he should know about the minerals mentioned, but are rather meant to serve as reminders to him of some characters which are employed in recognition.

Quartz, a crystalline form of silica (chemically, silicon dioxide, SiO_2) occurs in acid igneous rocks, often (as in granite) as a visible constituent. In sedimentary rocks it is frequently present as palpable grains in sands and sandstones, and as finer impalpable particles in silts and in rocks derived from silts. In metamorphic

Here are seen mineral grains produced by the decay of rocks. (Such grains are therefore often called *detrital* grains.) Forty times natural size, magnified by the microscope. *Drawn by S.G.B.-B.*

Q, Quartz; O, Orthoclase; P, Plagioclase, under ordinary light; PX, Plagioclase, under doubly-polarized light; R, Rutile: S, Staurolite; T, Tourmaline; L, Limonite; Z, Zircon.

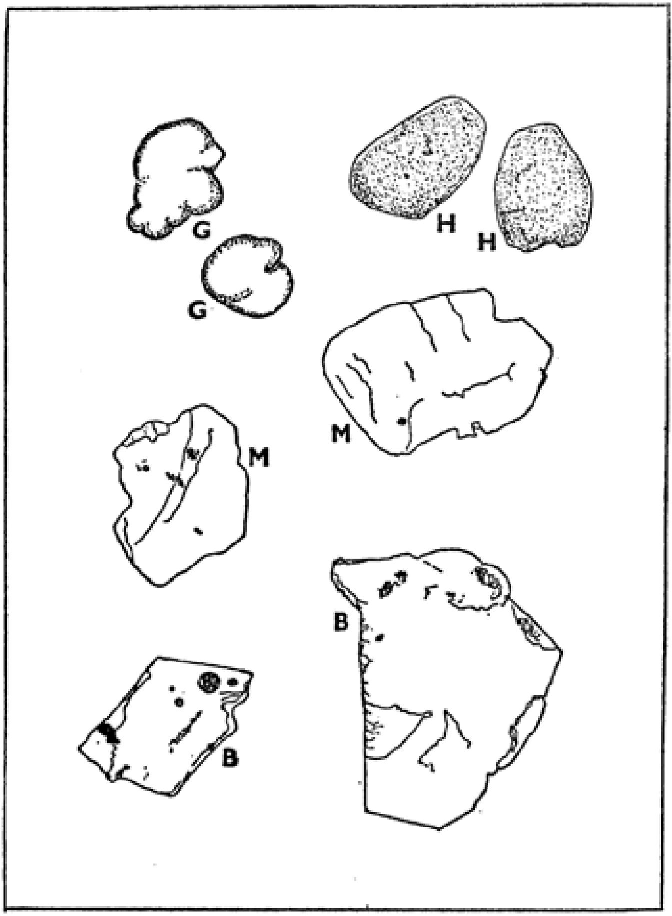


Figure 77.

The Microscopic Examination of Minerals.

Mineral grains released by rock decay. These detrital grains are here seen forty times natural size. *Drawn by S.G.B.-B.*

G, Glauconite; H, Hematite; M, Muscovite Mica; B, Biotite Mica.

QUARTZ.

rocks it is visible to the naked eye as a constituent of coarse-grained rocks such as gneiss and is commonly met with in other metamorphic materials, in a massive form in quartzite and fine-grained in many schistose rocks. As a disintegration product of rocks it occurs as grains of palpable size forming sand in soils, and as small impalpable particles forming silt. When palpable, sand gives a gritty feeling to the soil when a handful is rubbed between the fingers. As silt it gives a sensation of silkiness when handled. Quartz is of special importance in soils, when present as sand, in reducing cohesion and in promoting their free working in agricultural operations.

Quartz is recognized in hand specimens of the mineral by its hardness (7 in Mohs' scale of hardness, which means it will scratch glass), vitreous lustre, resistance to acid, by the shape of crystal and by its specific gravity, which is about 2·6. It can be identified in hand specimens of rocks by its hardness, transparency, vitreous lustre and resistance to acid. In thin sections under the microscope, especially noticeable are the characteristic "clouds" of inclusions, and important additional points are absence of alteration and cleavage, the low refractive index (near that of Canada balsam) and, under crossed Nicols, characteristic interference tints and an absence of twinning. In grains under the microscope the common shape is seen to be sub-angular and irregular (wind-worn grains may be spherical). The mineral is usually colourless but turbid, though free from decomposition. Sharply defined inclusions may be present. Confusion with felspars is possible, but lack of twinning and of cleavage in quartz help to distinguish it.

Orthoclase, a monoclinic potash felspar (chemically

potassium aluminium silicate, $KAlSi_3O_8$), is an important constituent of the granitic and syenitic divisions of the igneous rocks. It weathers readily and is consequently absent from most sedimentary rocks. Among metamorphic rocks it is found in gneiss. In soils it is to be expected in areas where

ORTHOCLASE.

orthoclase-bearing rocks are undergoing disintegration. The weathering of felspars ultimately produces minutely divided and colloidal materials which are important constituents of clay-rocks and heavy soils. Silt is frequently rich in finely comminuted felspars. The mineral is recognized in hand specimens by hardness, transparency, colour, and its stony appearance in association with crystal faces. In thin sections under the microscope absence of colour, low refractive index and the presence of alteration clouds help in diagnosis. There are two sets of cleavage at right angles, and, under crossed Nicols, simple twinning and characteristic interference colours are seen. Of grains under the microscope the common shape is irregular and sometimes cleavage is visible; other characters are absence of colour and low refractive index. Alteration products (muscovite, kaolinite) sometimes cloud the grain. Confusion with quartz is possible, but distinguishing points are refractive index, alteration and twinning. Orthoclase is distinguished from other felspars by the nature of the twinning.

Plagioclase is the general name of a series of felspars which includes as its extremes Albite, the soda plagioclase (chemically, sodium aluminium silicate, $NaAlSi_3O_8$) and Anorthite, the

PLAGIOCLASE.

lime plagioclase (chemically, calcium aluminium silicate, $CaAl_2Si_2O_8$).

The plagioclase felspars, as a whole, form a series of mixtures of Albite and Anorthite.

Representing Albite as Ab and Anorthite as An, we have the following series:—

			Range of Composition		
			Ab.An.		Ab.An.
Albite ..	$Ab_1\ An_0$ to $Ab_6\ An_1$	..	6 : 0	to	6 : 1
Oligoclase	$Ab_6\ An_1$ to $Ab_3\ An_1$	..	6 : 1	to	6 : 2
Andesine ..	$Ab_3\ An_1$ to $Ab_1\ An_1$	..	6 : 2	to	6 : 6
Labradorite	$Ab_1\ An_1$ to $Ab_1\ An_3$	..	6 : 6	to	2 : 6
Bytownite	$Ab_1\ An_3$ to $Ab_1\ An_6$	..	2 : 6	to	1 : 6
Anorthite ..	$Ab_1\ An_6$ to $Ab_0\ An_1$	..	1 : 6	to	0 : 6

Plagioclase is found, among igneous rocks, in diorite and gabbro and the corresponding hypabyssal and volcanic rocks. In sedimentary rocks it occurs in felspathic sandstones. In hand specimens of the minerals and of rocks the following characters are useful for determination: may be recognized as felspars by the dull to pearly lustre (stone-like) and sometimes by the twinning bands seen on the crystal faces under reflected light, colours are white, grey or pink, translucent, often shewing angular fracture, light in weight (specific gravity about 2·7), fairly hard (5 to 6½ in Mohs' scale of hardness). In thin sections under the micrsocope, plagioclase has the general characteristics of felspars, and under crossed Nicols often exhibits the diagnostic multiple twinning. In grains under the microscope, the common shape is irregular, sometimes shewing cleavage. The minerals are colourless with low refractive index (Albite 1·53, Anorthite 1·58—Canada balsam 1·55). Alteration products are often present. Plagioclase, as grains, may be confused with other felspars or with Quartz, but the multiple twinning seen under doubly polarized light is diagnostic.

Biotite is dark or ferro-magnesian mica (chemically, ferro-magnesian silicate with some water, (H_2K_2) (Al_2Fe_2) $(Mg.Fe_2)$ (Si_3O_{12}). An essential constituent of granite, it occurs frequently in other igneous rocks. Easily altered by the addition of water and by replacement of alkaline metals by hydrogen. Found in some metamorphic rocks (e.g. biotite gneiss). In hand specimens it is distinguished from Muscovite by its dark colour. In thin sections of rock under the microscope it may be recognized by the ragged ends of prismatic sections, by strong basal cleavage, by its colour and pleochroism. Greatest absorption occurs when cleavages are parallel with the short diagonal of the polarizer. Flakes under the microscope are seen as *ragged* plates (a distinction from Muscovite). Striations and inclusions are common.

BIOTITE.

Muscovite is white or potassium mica (chemically, aluminium potassium silicate with some water—$Al_6K_2H_6S_4O_{24}$—typically lacking iron and magnesium). It occurs frequently in granite and in many sedimentary and metamorphic rocks and soils. It is one of the least alterable of minerals. Micas occur as easily detached flexible plates which result from the strong basal cleavage. In hand specimens of the mineral, lack of colour and the softness of the crystals are noteworthy (hardness 2 to 2½ in Mohs' scale).

MUSCOVITE.

In hand specimens of rocks the flakes of the mineral are readily seen. Thin sections of rock under the microscope exhibit the ragged ends of prismatic sections of muscovite, strong basal cleavage and absence of colour, together with high interference tints under doubly polarized light.

Flakes from rocks and soils, under the microscope, are seen as *rounded* plates (a distinction from Biotite) and are colourless. The refractive index is low. The apparent size of the particles is often three or four times that of associated grains. Inclusions are common. Sericite is a form of muscovite, which has been constituted during the formation of sedimentary rocks or soils.

TOURMALINE.

Tourmaline is a complex silicate containing boron and aluminium. It commonly occurs in prismatic crystals which vary very much in colour, and the mineral may be transparent to opaque. The lustre of tourmaline is resinous and its fracture commonly uneven. It is a hard mineral (hardness 7).

It is widespread in rocks.

Under the microscope grains may be seen to be well rounded or prismatic or irregular. The refractive index is high. Inclusions are common but the grains are free from decomposition. Striations parallel to the principal crystallographic axis may be seen. The mineral is pleochroic.

RUTILE.

Rutile (chemically, titanium dioxide, TiO_2) usually occurs in a prismatic form vertically striated or as needles. Brownish-red is its typical colour. Its lustre is peculiar and adamantine. The fracture is commonly uneven. It is a fairly hard mineral (hardness 6). Rutile occurs in acid igneous rocks, in some gneisses, in some slates, and, since it is resistant to decomposition, in sedimentary rocks.

In examining grains under the microscope, colour and high refractive index are important; striations oblique to the length of prismatic grains may be seen:

these diagonal striations are characteristic. Inclusions are rare.

Zircon (chemically, zirconium silicate, ZrO_2SiO_2). The common shape of the crystal is prismatic with pyramidal ends. It may be colourless or yellow to purple or green. It has adamantine lustre, the fracture is generally conchoidal. It is a heavy mineral, the specific gravity being about 5. It is hard (hardness 7½). Zircon is widely distributed in igneous and metamorphic rocks, and being hard and resistant to change, is widespread in sedimentary rocks, and, no doubt, in soils. Study of grains under the microscope will take note of the high refractive index, the shape of the crystals—often elongate (prismatic) with a tendency to shew the pyramidal ends. Fractured grains are rounded. Clarity, lustre and translucency are typical and inclusions are common.

ZIRCON.

Glauconite (chemically, potassium iron aluminium silicate with water) is amorphous.—Typically green and often opaque, it has a greasy to earthy lustre, and the fracture is commonly earthy and irregular. It is a soft substance (hardness 2). It occurs in sedimentary rocks, particularly in many of Cretaceous age, characteristically in the Greensands. It is present in soils derived from such rocks. In hand specimens of rocks it frequently appears in minute irregular grains giving a speckled appearance to such light-coloured materials as " Kentish Rag " (limestone of Hythe Beds, Lower Greensand). When grains are examined under the microscope they are often seen to be opaque, greenish, irregularly rounded masses.

GLAUCONITE.

Staurolite (chemically, hydrous iron aluminium silicate with some replacement by magnesium, manganese and ferric iron).—The mineral is brown with sub-vitreous lustre. The fracture may be sub-conchoidal and jagged. It is hard (hardness 7).

STAUROLITE.

Staurolite occurs in metamorphic rocks and in sedimentary rocks derived from them. Under the microscope grains may appear platy with irregular outline and jagged fracture, or may be rounded. The colour is typically yellow and pleochroism is exhibited. The refractive index is high. Sometimes decomposition occurs.

Magnetite is an important ore of iron when it occurs in bulk (chemically a mixture of two oxides of iron, $FeO.Fe_2O_3$).—It is black, with metallic lustre, and commonly exhibits a jagged fracture. It is very heavy (specific gravity about 5) and fairly hard (hardness 6). Widely distributed in comparatively small quantities in many igneous rocks, it is naturally most to be expected in basic rocks. Found in metamorphic rocks. In hand specimens the mineral is recognized by colour and mode of crystallization, and by properties just mentioned. In rock slices under the microscope it is recognized from being black and opaque (transmitted light) and by having a characteristic silver grey metallic lustre (reflected light). Grains under the microscope are recognized by shape, opacity, colour and jagged fracture. From other detritals this mineral can be separated by the use of a bar magnet.

MAGNETITE.

Hematite (chemically, an oxide of iron, Fe_2O_3) is an opaque mineral, steel-grey to red in colour and with a metallic to earthy lustre. Its fracture is usually irregular. It is heavy (specific gravity about 5) and is

HEMATITE.

fairly hard (hardness 6). It is a widespread mineral in igneous, seditary and metamorphic rocks. It occurs as a cement in red sandstones which owe their colour to it. Under the microscope grains may appear rounded and earthy, reddish-brown (by reflected light) and opaque.

LIMONITE.

Limonite, a colloidal mineral (chemically, regarded as a hydrated oxide of iron, $2Fe_2O_33H_2O$) of irregular shape, brown in colour and opaque, with a submetallic to earthy lustre. It breaks with an uneven fracture, is fairly heavy (specific gravity about 4, and of medium hardness (5). This substance is always of secondary origin, being a common alteration product of iron-bearing minerals. It is a cement of yellow and brown sandstones; water containing iron compounds in solution often deposits limonite. In hand specimens the colour and streak (yellowish-brown) are characteristic. Mineral grains are irregular in shape, opaque, and yellow to brown by reflected light.

OUTLOOK

The intelligent farmer wishes to make the best possible use of all the scientific information that is available. He wishes this in order to be an efficient farmer, successful in his business. This is the farmer's point of view and, as far as soils are concerned, it is a matter of considerable moment, as a backward glance over these pages will shew. But there is a national point of view too, and it must be recognized that wherever science can make a contribution to success it is in the national interest, much more sometimes than in the farmer's interest, that the findings of science should be applied in the industry. As far as the agricultural land of our country is concerned, it is of great national importance that the good soil of the nation should be protected against erosion and undue depletion of its food reserves, that fertilizers and manures should be employed properly, and that every soil having been correctly cultivated, should grow the range of crops for which it is best suited when due regard has been paid to all the factors involved. Here, not only has the question of the most suitable crops to be considered but also the demand for them, and the facilities for their distribution to the consumer. As we look forward it is in the hope that pedology will make a still greater contribution in the future to the success of agriculture, and will play its part in the great work of bringing about a condition of world affairs in which the men, women and children of all races may have the living conditions and cultural advantages which have so far been the limited privilege of the fortunate

APPENDICES

APPENDIX I.—GENERALIZED TABLE OF THE IGNEOUS ROCKS.

Mineralogical and chemical composition of the rocks in each of the columns.	ORTHOCLASE with Quartz and Mica.	ORTHOCLASE with Hornblende	PLAGIOCLASE with Hornblende.	PLAGIOCLASE with Augite.	OLIVINE Etc.
	Acid	Sub-Acid	Sub-Basic	Basic	Ultra-Basic
	Silica over 66%	Silica, 66–62%	Silica, 62–52%	Silica, 52–45%	Silica, 45–35%
GLASSY	Rhyolite Glass (a)	Trachyte Glass (a)	Andesite Glass (a) (b)	Basalt Glass (b)	Peridotite Glass (b)
VOLCANIC	Rhyolite (c)	Trachyte (c)	Andesite (c)	Basalt	Magma Basalt
HYPABYSSAL	Granite Porphyry	Syenite Porphyry	Diorite Porphyrite	Dolerite	Hypabyssal Peridotite
PLUTONIC	Granite	Syenite	Diorite	Gabbro	Plutonic Peridotite

It must be clearly understood that such an exposition of the classification only serves to indicate the main principles involved and to explain the terms. Details should be sought in works on Petrology.

(a) Glasses in the Acid half of the table are included under the general term Obsidian.
(b) Glasses in the Basic half of the table are included under the general term Tachylyte.
(c) Rhyolite, Trachyte and Andesite, when very finely crystalline, are collectively called Felsite.

APPENDIX II.—GEOLOGICAL CHRONOLOGY.

Names of the Geological Periods.		These letters (a to l) are used on British geological maps	Approximate duration of each period in millions of years.	Characteristics of the Periods.
Post Tertiary or Quaternary	Holocene or Recent and Prehistoric			Iron used from 500 B.C. Bronze used from 2,000 B.C. Neolithic Man from 18,000 B.C. — 20,000 years ago.
Tertiary or Cainozoic	Pleistocene	(l)	1	Ice-age. Modern Man. Palaeoliths.
	Pliocene	(k)	5	Man. Eoliths.
	Miocene		10	
	Oligocene	(i)	10	
	Eocene	(i)	24	Modern Invertebrates occur.
Secondary or Mesozoic	Cretaceous	(h)	50	Maximum Sea.
	Jurassic	(g)	30	Flowers begin. Birds begin.
	Triassic	(f)	30	Mammals begin.
Primary or Palaeozoic	Permian	(e)	40	Maximum Land. Reptiles begin. Ice-age (South).
	Carboniferous	(d)	70	Characteristic Plants. Amphibia begin.
	Devonian and Old Red Sandstone	(c)	45	Fishes begin.
	Silurian	(b)	30	Air-breathers and Land Plants begin.
	Ordovician	(b)	75	
	Cambrian	(a)	80	Varied Marine Fauna. Ice-age (China, etc.).
Pre-Cambrian			500	Many earth movements have destroyed the fossil record.

Each period except the Pre-Cambrian is characterised by its own "association" of fossils.
By the cooling of molten material, igneous rocks have been produced side by side with the deposition of sediment in all geological periods.

APPENDIX III

Mohs' Scale of Hardness.

1. Talc.

    ←——————— Finger-nail.

2. Rock Salt, Selenite, Gypsum.
3. Calcite.

    ←——————— Penny.

4. Fluorspar.
5. Apatite.
6. Orthoclase.

    ←——————— Glass.

7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

The composition of the substances in the scale is as follows:—1, Hydrous magnesium silicate; 2, Rock salt is sodium chloride, Selenite and Gypsum are hydrated calcium sulphate; 3, Calcium carbonate; 4, Calcium fluoride; 5, Calcium phosphate with chlorine or fluorine; 6, Monoclinic potassium felspar, i.e., potassium aluminium silicate; 7, Silicon dioxide; 8, An aluminium fluorine silicate; 9, Alumina, Al_2O_3; 10, Carbon.

Example of use: Orthoclase (6) will scratch Apatite (5) and is itself scratched by Quartz (7) and also by glass—or a steel penknife (hardness between 6 and 7).

APPENDIX IV

Soil Texture.

English soil-surveyors frequently employ a system of textural nomenclature in some respects simpler than that of the official American system, part of which has been considered in detail in this book, pages 142–149. Mr. Basil S. Furneaux, M.Sc., has drawn up the following table of correlation between the two nomenclatures.

American System.

The texture grades under the American System have definite names which must not be modified or elaborated. In the U.S.A. Soil Survey limits of mechanical composition are laid down for each texture grade and the texture descriptions of each surveyor are regularly checked in the laboratory.

English System.

A certain amount of elasticity is claimed for the English System in that it is permissible for surveyors to modify or elaborate their texture descriptions if they feel that the soil condition demands it.

American System	*Symbol.*	English System
1. Coarse Sand .. 2. Sand .. 3. Fine Sand .. 4. Very Fine Sand ..	Sa.	Light Sand[1]
5. Loamy Coarse Sand 6. Loamy Sand .. 7. Loamy Fine Sand 8. Loamy Very Fine Sand	Sb.	Heavy Sand[1]
9. Coarse Sandy Loam 10. Sandy Loam .. 11. Fine Sandy Loam 12. Very Fine Sandy Loam	La.	Light Loam[1]
13. Loam	Lm.	Loam[2]
(Silty Loam)[3]	Lb.	Heavy Loam[4]
14. Silt Loam	Za.	Light Silt[4]
15. Sandy Clay Loam[5] ..	——————	

American System.		English System.	
		Symbol.	
16. Clay Loam	.. ..	Zm.	Medium Silt
17. Silty Clay Loam	..	Zb.	Heavy Silt
18. Sandy Clay[5]	.. ..	———	
19. Clay	.. .. ..	Cs.	Silty Clay[6]
20. Silty Clay	.. ..	sC.	Clay[6]
———	.. ..	C.	Calcareous Soil[7]
———	.. ..	Pk.	Peat[8]

1. Qualifying descriptions of size of sand particles may be prefixed.
2. Frequently called "Medium Loam," but word economy leads to its abbreviation.
3. Not included in the Official Texture Scale, but is sometimes used. A useful grade.
4. These two texture grades correspond roughly with "Silt Loam" in the American system; "Heavy Loam" (Lb.) corresponding with "Silty Loam" where that grade is used.
5. These textures are not used under the English System. Where sand is present in a heavier than loam grade it may be noted by a qualifying prefix to the appropriate texture grade. Under the American System it is permissible to prefix the size of sand particle, e.g. Coarse Sandy Clay.
6. These two grades are so given in the First Report of the Soils Correlation Committee (1931), but Clarke (*The Study of the Soil in the Field*, 2nd. Ed., 1938, p. 180) gives the one grade "C. Clay." He ignores the "C. Calcareous Soil," listed in the First Report mentioned above.
7. Additional textural description listed in the First Report of the Soils Correlation Committee. It should not be confused with the "C. Clay" of Clarke (see note 6 above). The American System makes no provision for the peculiarities of texture imparted by the presence of high lime concentrations. It assumes that, when present, these will appear in the series descriptions.
8. Peat as a texture grade does not appear in the American Scale.

APPENDIX V

Guide to Liming Based on Soil Analysis.

I am indebted to Dr. N. H. Pizer for the following notes on Lime:—

LIME is removed from the soil in drainage water and in crops. Continual removal of lime without replacement results in a soil becoming increasingly ACID. Soil acidity is a common cause of CROP FAILURES. The condition of acidity of a soil is shewn by the pH VALUE as follows:—

Below 4·8	extremely acid.
4·8 to 5·2	strongly acid.
5·3 to 5·7	moderately acid.
5·8 to 6·4	slightly acid.
6·5 to 6·9	very slightly acid.
Above 6·9	absence of acidity.

Most cultivated soils fall within the pH range of 4·5 to 7·5.

Crops differ in their ability to withstand acid conditions. Most crops prefer slightly acid to neutral conditions. None will grow in extremely acid soil. Chicory, kale, lupins, oats, potatoes, rye, rye-grass, tomatoes, apples, gooseberries and strawberries are able to grow in strongly acid soil, but prefer moderately to slightly acid conditions; other crops are likely to fail. Beans, broccoli, cabbage, cauliflower, maize, onions, swedes, turnips, wheat and white clover will grow in moderately acid soil but prefer less acid conditions. The remaining fruit crops prefer slightly acid conditions, and the remaining arable and vegetable crops slightly acid to neutral conditions.

Acidity is reduced by applying lime. The amount of lime (CaO) in cwts. per acre required to bring the pH value between 6·0 and 6·5 is known as the LIME-REQUIREMENT (L.R.) of the soil. It is generally advisable not to remove acidity completely. Deficiency of manganese, iron or boron may result if this is done.

Large lime-requirements of 2 tons or more are best applied in two dressings. On arable fields the first dressing might be applied and disced in before ploughing and the second after ploughing. Even spreading is necessary. When the lime-requirement has been satisfied, about 10 cwt. CaO per acre

should be applied every four years to replace losses sustained by drainage and by removal in crops.

The different forms of agricultural lime vary in lime (CaO) content and allowance must be made for this, e.g. if the lime requirement is 20 cwt. CaO per acre, $20 \times \frac{100}{80} = 25$ cwt. of ground lime containing 80 per cent. CaO or $20 \times \frac{100}{50} = 40$ cwt. of ground carbonate of lime containing 50 per cent. CaO should be applied. The CaO (lime) content must be known.

If the lime that is used is coarsely ground or lumpy, larger dressings will be required to obtain even distribution, and the same effect as from a finely ground lime. The following quantities have roughly the same effect as 1 ton of ground quicklime:—

2 tons	Lump Lime.	4 tons	By-product Lime.
2½ ,,	Small Lime.	4 ,,	Crushed Chalk.
3 ,,	Limestone Dust.	5 ,,	(minimum) Small Chalk.

APPENDIX VI

THE LITERATURE OF THE SOIL.

It is impossible to deal adequately in a small space with such a vast subject as that of the literature of soil studies. G. W. Robinson in *Soils, their Origin, Constitution, and Classification*, London: Murby (first published, 1932) gives detailed references at the ends of his chapters, and these lists constitute classified guides to further sources of information. G. R. Clarke's *The Study of the Soil in the Field* Oxford: Clarendon Press (first published, 1936) must be mentioned as a very useful guide to practical pedology. Classified lists of some useful books are included. J. S. Joffe in *Pedology*, New Brunswick: Rutgers University Press (first published, 1936) gives classified lists of references to the literature. *Soils and Men, Year Book of Agriculture*, 1938 (U.S. Department of Agriculture) is a symposium of the greatest interest to the student of the soil, and the literature cited includes more than 480 items.

INDEX AND GLOSSARY

[Where no explanation of a term is given it is generally fully explained in the text at the page, or pages, indicated.]